Chapter 5
Academic Research and Development: Financial and Personnel Resources, Integration With Graduate Education, and Outputs

Contents

Highlights

Financial Resources for Academic R&D

- **In 1997, an estimated $23.8 billion (in current dollars) was spent for research and development (R&D) at U.S. academic institutions ($21.1 billion in constant 1992 dollars).** The Federal Government provided $14.2 billion; academic institutions, $4.4 billion; state and local governments, $1.8 billion; and industry and other sources each provided $1.7 billion.

- **Industrially performed R&D grew faster than academic R&D between 1994 and 1997,** and the academic sector's share fell to 12 percent, reversing a decade-long trend of an increasing role for academic performers in total U.S. R&D. Between 1984 and 1994, academia had risen from a 9 percent share to a 13 percent share of total U.S. R&D performance.

- **The academic sector performs over 50 percent of basic research, continuing to be the largest performer of basic research in the United States.** Academic R&D activities are concentrated at the basic research end of the R&D spectrum. Of estimated 1997 academic R&D expenditures, an estimated 67 percent went for basic research, 25 percent for applied research, and 8 percent for development.

- **The Federal Government continues to provide the majority of funds for academic R&D.** It provided an estimated 60 percent of the funding for R&D performed in academic institutions in 1997, down from about 65 percent in the early 1980s. Although nonfederal support increased more rapidly than federal through most of the 1980s, this trend was reversed in the first half of the 1990s. Federal support has grown more slowly than nonfederal in both 1996 and 1997, however.

- **Federal obligations for academic R&D are concentrated in three agencies: the National Institutes of Health (NIH—57 percent), the National Science Foundation (NSF—15 percent), and the Department of Defense (DOD—10 percent).** The National Aeronautics and Space Administration (6 percent), the Department of Energy (5 percent), and the Department of Agriculture (3 percent) provide an additional 14 percent of obligations for academic R&D. Federal agencies emphasize different science and engineering (S&E) fields in their funding of academic research. Several agencies concentrate their funding in one field; others have more diversified funding patterns.

- **There has been a significant increase in the number of universities and colleges receiving federal R&D support during the past two decades,** with almost the entire increase occurring among other than research and doctorate-granting institutions. In 1995, 654 of these institutions received R&D support from the Federal Government, compared to 422 in 1985 and 335 in 1975.

- **After the Federal Government, the academic institutions performing the R&D provided the second largest share of academic R&D support.** The institutional share grew from about 14 percent of academic R&D expenditures in the early 1980s to an estimated 19 percent in 1997. Some of these funds directed by the institutions to research activities derive from federal and state and local government sources, but—since they are not restricted to research and the universities decide how to use them—they are classified as institutional funds.

- **Industrial R&D support to academic institutions has grown more rapidly than support from all other sources in recent years.** In constant dollars, industry-financed academic R&D increased by an estimated average annual rate of 8.1 percent between 1980 and 1997. Industry's share grew from 4 percent to an estimated 7 percent during this period.

- **Total academic S&E research space increased by almost 22 percent between 1988 and 1996,** up from about 112 million to 136 million net assignable square feet. When completed, construction projects initiated between 1986 and 1995 are expected to produce 52 million square feet of new research space, equivalent to about 39 percent of existing space.

- **In 1996, 55 percent of research-performing institutions reported construction or repair/renovation projects that were needed but had to be deferred because funds were not available.** The cost of these deferred projects was $9.3 billion. Sixty percent of the needs reported were for construction and 40 percent were for repair/renovation.

- **Expenditures for academic research instrumentation in U.S. research universities began increasing recently.** This increase follows a pattern of large increases in investment throughout most of the 1980s, followed by a steady decline of about 2 percent a year between 1989 and 1993. Annual research equipment expenditures as a percentage of total R&D expenditures declined from 7.2 percent in 1986 to 5.2 percent in 1993 before rising again to 5.6 percent in 1995.

- **Computers and data handling equipment represented 19 percent of the number of instruments in the national stock and 30 percent of total aggregate cost.** There were an estimated 61,684 instruments with an estimated aggregate original purchase price of $6.255 billion in the stock of research instruments at the 318 colleges, universities, and medical schools represented in the National Survey of Academic Research Instruments and Instrumentation Needs in 1993.

The Academic Doctoral S&E Workforce

- **The 217,500 academic doctoral scientists and engineers in 1995 represented the largest number ever employed in the academic sector.** But employment growth for this highly trained group was stronger in other parts of the economy, and the academic sector's employment share stood at 46 percent—a record low.

- **Full-time doctoral S&E faculty numbered an estimated 171,400 in 1995, a decline from 173,100 in 1991.** Full-time faculty represented 79 percent of academic doctoral S&E employment in 1995, down from 88 percent in 1973. Much of the decline occurred among those with the rank of full professor.

- **The number of women with S&E doctorates who held academic positions increased to 52,400 in 1995.** This represented a new high to 24 percent of total academic employment of doctoral scientists and engineers. Women remained highly concentrated in the life and social sciences and psychology.

- **Minority employment continued to grow and reached 35,300 in 1995, but stayed at low levels for some groups.** The 12,800 members of underrepresented groups—black, Hispanic, Native American, and Alaskan Native—accounted for 6 percent of academic doctoral scientists and engineers, up from 2 percent in 1973. Asian employment in 1995 stood at 22,500, or 10 percent of the total; this was up from 4 percent in 1973.

- **Women and members of minority groups have tended to enter academic employment in line with or above their proportion of recently awarded S&E doctorates.** Among recent Ph.D. recipients in academic employment—doctorates awarded in the preceding three years—women and underrepresented minorities were employed in rough proportion to their share of newly awarded doctorates to U.S. citizens and permanent visa-holders; Asians—many of whom are foreign-born—were represented well in excess of their share of new S&E Ph.D.s.

- **The progressive aging of the doctoral academic S&E workforce, evident over much of the past two decades, appears to have leveled off.** The mean age of full-time doctoral faculty rose from 42.5 years in 1973 to 47.1 years in 1989 and stood at 47.4 years in 1995, suggesting gradual hiring for the system as a whole as faculty retire. However, for young Ph.D.s, this has to be seen in the context of a steep increase in newly awarded doctorates—from about 22,700 in 1989 to 27,800 in 1995.

- **An estimated 26,900 recent Ph.D. recipients—doctorates awarded in 1992-94—entered academic employment in 1995. But the meaning of academic "employment" has changed for these young doctorate-holders.** Fewer than 45 percent had regular faculty appointments, compared with over 75 percent in the early 1970s, while the proportion in postdoctorate positions rose from 13 to 40 percent.

- **The physical sciences have grown more slowly than other fields in terms of overall doctoral employment—29,300 in 1995—and doctorates in full-time faculty positions.** Their doctoral employment share fell from 19 percent in 1973 to 13 percent in 1995. The life sciences, engineering, and psychology gained employment shares.

Work Responsibilities of Academic Doctoral Scientists and Engineers

- **The academic doctoral S&E research workforce—defined as those whose primary or secondary work responsibility was research—numbered an estimated 153,500 in 1995, up from 80,000 to 90,000 during the 1970s.** The highest levels of research participation, so defined, were found in engineering and the environmental sciences; the lowest in mathematics, psychology, and the social sciences.

- **In 1995, 39 percent of the academic doctoral workforce—85,700—reported having research support from the Federal Government during the week of April 15.** This compares with 37 percent in 1993. A sizable fraction of those with federal funding—26 percent—obtained their support from more than one agency.

- **The number of those reporting teaching as their primary activity has fluctuated around the 100,000 mark since 1985. In contrast, those designating research as primary rose from 56,000 to 83,000 over the period.** In 1995, 46 percent of respondents reported teaching as their primary work responsibility, compared with 38 percent who reported research.

- **Doctoral S&E employment growth in Carnegie research universities was largely confined to those identifying research as their primary activity**—from 17,500 in 1973 to 45,900 in 1995. In other types of institutions, the number choosing research grew from 10,300 to 37,100 over the period.

Integration of Research With Graduate Education

- **In 1995, for the first time in almost two decades, enrollment of full-time S&E graduate students declined slightly.** The enrollment decline was irrespective of primary source of support. The numbers of full-time graduate students with primary support from the Federal Government, nonfederal sources, or their own resources (self-support) all declined.
- **The proportion of full-time graduate students in S&E with a research assistantship as their primary mechanism of support has increased considerably.** Research assistantships were the primary support mechanism for 66 percent of the students whose primary source of support was from the Federal Government in 1995, compared to 55 percent in 1980. For students whose primary source was nonfederal, research assistantships rose from 20 percent to 29 percent of the total during this period. The overall number of graduate students with a research assistantship as their primary mechanism of support increased every year between 1985 and 1994 before declining slightly in 1995.
- **The Federal Government plays a larger role as the primary source of support for some support mechanisms than for others.** A majority of traineeships in both private and public institutions (53 and 73 percent, respectively) are financed primarily by the Federal Government, as are 60 percent of the research assistantships in private and 47 percent in public institutions.
- **NIH and NSF have been the primary source of federal support for full-time S&E graduate students relying on research assistantships as their primary support mechanism.** From the early 1970s to the late 1980s, NSF was the federal agency that was the primary source for graduate research assistantships. It was surpassed by NIH in 1993. Between 1972 and 1995, the proportion of federal graduate research assistantships financed primarily by NSF declined from one-third to less than one-quarter, while the proportion financed primarily by NIH increased from one-sixth to one-quarter.
- **Research assistantships are more frequently identified as a primary mechanism of support in the physical sciences, the environmental sciences, and engineering than in other disciplines.** Research assistantships comprise more than 50 percent of the primary support mechanisms for graduate students in astronomy, atmospheric sciences, oceanography, agricultural sciences, chemical engineering, and materials engineering. They account for less than 20 percent in the social sciences, mathematics, and psychology.

Article Outputs From Scientific and Engineering Research

- **In 1995, about 142,800 scientific and technical articles were published by U.S. authors in a set of journals included in the Science Citation Index (SCI) since 1981. The bulk—71 percent—were by academic authors**. Eight percent each had authors affiliated with other major sectors: industry, government, and nonprofit organizations.
- **Publications by U.S. industrial authors rose strongly in life science fields—clinical medicine, biomedical research, and biology—and constituted nearly half of industry publications; this was up from 19 percent in 1991.** From the late 1980s on, industry output in engineering and technology was lower than it had been in preceding years.
- **Increasingly, scientific collaboration in the United States involves scientists and engineers from different employment sectors. In 1995, just under one-quarter of all academic papers involved such cross-sectoral collaboration**—6 percent with industry, 8 percent each with the federal and not-for-profit sectors, 3 percent with federally financed research and development centers, and 2 percent with other sectors. In the other sectors, well over half of their cross-sector collaborations involved academic authors.
- **Globally, five nations produced more than 60 percent of the 439,000 articles in the SCI set of journals in 1995:** the United States (33 percent), Japan (9 percent), the United Kingdom (8 percent), Germany (7 percent), and France (5 percent). No other country's output reached 5 percent of total.
- **The development or strengthening of national scientific capabilities in several world regions was evident in faster publications output growth elsewhere than in the United States; growth elsewhere accelerated toward the mid-1990s, overshadowing continued growth in U.S. output.** This continued a long-term decline in the U.S. share of total article output.
- **Europe accrued gains in output share—from 32 percent in 1981 to 35 percent in 1995. Asia's share rose from 11 to 15 percent,** even though India's output declined by one-third in absolute number of articles over the period.
- **The number of articles in physics, earth and space sciences, and biomedical research increased the most rapidly—by 63, 36, and 30 percent, respectively—from 1981 to 1995.** The output volume of articles in chemistry, clinical medicine, and engineering and technology was little changed; those for mathematics and biology declined.

- **Great variation marked countries' article outputs per billion U.S. dollars of their estimated 1995 gross domestic product.** Israel and some smaller European nations ranked highest, exceeding 30 articles per billion. The United States was in the middle range, with 20 articles. Nations with fast-developing economies had smaller than expected article outputs, reflecting the recent rapidity of their economic strides and suggesting considerable room for further scientific growth.

- **Countries' science portfolios, as reflected in their published output, show some striking differences.** Clinical medicine and biomedical research are heavily emphasized in the article outputs of the United States, United Kingdom, the countries of Northern Europe, several smaller Western European nations, and Chile. Chemistry and physics form a larger than average fraction of the output of France, Germany, Spain, Italy, Eastern Europe, Russia, Mexico, and many Asian countries. Russia, China, Egypt, and Asian countries emphasize engineering and technology.

International Collaboration and Citation of Research Outputs

- **The globalization of science is reflected in a pervasive trend in scientific publishing toward greater collaboration. In 1995, half of the articles in the SCI journals had multiple authors, and almost 30 percent of these involved international collaboration.** This trend affected all fields, and a steadily growing fraction of most nations' papers involved coauthors from different nations. By 1995, article outputs since 1981 had grown by 20 percent, the number of coauthored articles by 80 percent, and the number with international coauthors by 200 percent.

- **For almost every nation with strong international coauthorship ties, the *number* of articles involving a U.S. author rose strongly between 1981 and 1995.** Concurrently, however, many nations broadened the reach of their international collaborations, causing a diminution of the U.S. *share* of the world's internationally coauthored articles.

- **Citation patterns also mirror the global nature of the scientific enterprise, as researchers everywhere extensively cite research outputs from around the world.** U.S. scientific and technical articles as a whole are cited by virtually all mature scientific nations in excess of the U.S. output's world share. This holds for chemistry, physics, biomedical research, and clinical medicine. U.S. articles in other fields tend to be cited at or slightly below their world output share.

- **The number of article citations on U.S. patents increased from 8,600 in 1987 to 47,000 in 1996, and their field distribution shifted strongly toward the life sciences.** This rise in number of citations held for all fields and for papers from all sectors, with the fastest growth in citations to biomedical research and clinical medicine.

- **The number of academic patents, while small, rose more than sevenfold in just over two decades—from about 250 annually in the early 1970s to more than 1,800 in 1995—and the number of academic institutions receiving patents increased from about 73 in the early 1980s to 168 by the mid-1990s.** Academic patenting increased more rapidly than all annual U.S. patent awards. Among institutions with patents are a growing number of universities and colleges not traditionally counted among the research universities.

- **Academic patents are concentrated in fewer utility classes than patents overall; in fact, patents in only three utility classes with presumed biomedical applicability constituted more than a quarter of all academic patents in 1995.** Revenue from academic patenting reached $299 million in 1995.

Introduction

Chapter Background

The academic research and development (R&D) enterprise has enjoyed strong growth for the past decade but is facing some issues arising partly from its own success, partly from changes in its environment.

The nation's universities and colleges continue to perform more than half of U.S. basic research. Though faced with severe financial pressures, their own R&D funds are nearing one-fifth of their total R&D expenditures. At the same time, industry relies increasingly on academic R&D. There is more collaboration between industrial and academic researchers, and patent citing to academic publications is increasing. Industry support has grown, but remains well below 10 percent of the total funding of research in academia; furthermore, industry funding cannot be expected to become a mainstay of academic research funding.

The Federal Government continues to provide the majority of academic R&D support. Three agencies provide the bulk of these funds—the National Institutes of Health (NIH), the National Science Foundation (NSF), and the Department of Defense (DOD). NSF and DOD together provide much of the nation's R&D support for the physical and computer sciences, mathematics, and engineering.

Demographic projections point to the potential for strong enrollment growth over the next decade and the continuation of several trends: more minority participation, more older students, more nontraditional students. Foreign graduate students, however, may attend U.S. institutions in lesser numbers.[1] In this context, and driven by financial and other pressures, universities and colleges will continue to debate questions about their focus and mission. These discussions will take place against the backdrop of faculty retirements. An unresolved question is the extent and nature of replacement hiring into tenure-track faculty positions versus other, more temporary, appointments.

Urgent questions about the nature of graduate education are being raised. Is the current model the appropriate one, or should training allow for broader and more varied application of skills in the marketplace? Should students be given more autonomy from their professors, perhaps by way of restructuring their modes of support? What is the appropriate role for the Federal Government in this support? Continued increases in the number of foreign students, vital for many graduate programs, cannot be taken for granted. Thus, issues about the nature of graduate education join with questions of university missions and program organization.

The research universities are valued as a national resource. They educate and train large proportions of the nation's scientists and engineers, embody the model of integrated graduate training and research, and conduct much of the nation's basic research. Yet they face difficult questions. Is the nature of their graduate training up to the task of developing a high-quality yet flexible workforce of scientists and engineers? Is it driven too much by research? Is their research enterprise too insular, too driven by its own dynamic or external demands from the Federal Government or industry? Does it cost too much? How can research be better connected to undergraduate education? Other universities increasingly face these same questions, as the growth of the research function continues in institutional segments that have not traditionally been considered among the research universities.

Answers to these and other questions will emerge gradually, as individual institutions respond to the challenges and opportunities they perceive. The nation's universities and colleges have shown great ability to adapt to changed realities. In time, it will become possible to take stock of the changes and assess their extent. Many issues underlying these changes will persist, as higher education institutions try to find the appropriate balance among their many functions. (See "Developments Impinging on Academia.")

This chapter addresses several key aspects of the academic R&D enterprise including financial resources, physical infrastructure, science and engineering (S&E) doctoral employment, the integration of research and graduate education, and research outputs. The questions raised in the preceding discussion are difficult ones to resolve and relate to highly complex issues. This chapter, while not providing definitive answers to these questions, does provide data trends and analysis to assist decisionmakers in assessing these issues.

Chapter Organization

The chapter opens with a discussion of trends in the financial resources provided for academic R&D, including allocations across both academic institutions and S&E fields. Since the Federal Government has been the primary source of support for academic R&D for over half a century, the importance of selected agencies in supporting individual fields is explored in some detail. Data are also presented on changes in the number of academic institutions receiving federal R&D support. The section next examines the status of two key elements of university research activities—facilities and instrumentation. Topics explored include their funding, adequacy, and unmet needs.

The next section discusses trends in the employment, demographic characteristics, and activities of academic doctoral scientists and engineers. The discussion of employment trends focuses on full-time faculty and other positions. Trends in the involvement of women, underrepresented minorities, and Asians are explored, as are shifts in the faculty age structure. Special attention is given to participation in research by academic doctoral scientists and engineers and the federal support reported for these activities. Selected demographic characteristics of recent doctorate-holders entering academic employment are examined.

The third section looks at the relationships between research and graduate education. It covers overall trends in graduate support and patterns of support in different types of

[1] For a discussion of this point, see chapter 2, "Foreign Doctoral Students in the United States."

Developments Impinging on Academia

The nation's universities and colleges are facing changes in finances, enrollment, faculty, and environment whose eventual results cannot be foreseen with any degree of confidence. Cost pressures seem unabated; state funding to public institutions may benefit from a strong economy but faces competition from other uses. Overall enrollment in the nation's four-year colleges and universities declined somewhat in the early 1990s after rising during the preceding decade. However, the U.S. Department of Education projects rising numbers of students at U.S. universities and colleges over the coming decade or more, based on demographic projections and assumptions about cohort participation rates in higher education. The available evidence suggests that the racial/ethnic makeup of the student body will continue to change, and that women will continue to make inroads into fields that they have not traditionally entered. The number of foreign students, long a mainstay for many graduate programs in science and engineering, may decline as other countries develop their own programs. Faculty retirements are expected to rise, based on the age structure; but institutions' responses to this situation are not clear. Replacement hiring may take place, or some portion of the teaching burden may be shifted to temporary or nonfaculty employees. Media-based teaching and learning developments might affect the roles of teachers and of higher education institutions—and might perhaps even affect enrollments. State governments are looking at universities as regional economic development engines and sources of innovation, and the institutions themselves pay increasing attention to these types of activities.

Current discussions about university roles, structures, and priorities will need to take account of these and other factors. It is difficult to predict with any degree of precision the course of any one of these factors, much less their combined impacts on the future shape of the U.S. higher education enterprise as set in an increasingly skill-based society.

institutions, and compares support patterns for those who complete an S&E doctorate with the full population of graduate students. The extent of participation by graduate research assistants in academic research is examined, as are the sources of support for research assistants and the spreading incidence of research assistantship (RA) support to a growing number of academic institutions.

The chapter's final section deals with two research outputs: scientific and technical articles in a set of journals covered by the Science Citation Index (SCI), and patents issued to U.S. universities. (A third major output of academic R&D, educated and trained personnel, is discussed in the preceding section of this chapter and in chapter 2.) The section specifically looks at the output volume of research (article counts), collaboration in the conduct of research (joint authorships), use in subsequent scientific activity (citation patterns), and use beyond science (citations to the literature on patent applications).

Financial Resources for Academic R&D[2]

Adequate financial support for R&D activities at U.S. universities and colleges, as well as excellent research facilities and high-quality research equipment, is essential in enabling U.S. academic researchers to carry out world-class research. Since academic R&D is a significant part of the national R&D enterprise, this section focuses both on the levels and sources of support for R&D activities at U.S. universities and colleges as well as academic R&D facilities and instrumentation.

Overview[3]

In 1997, an estimated $23.8 billion was spent on R&D at U.S. academic institutions.[4] Academia's role as an R&D performer increased steadily between 1984, when this sector accounted—as it had for more than a decade—for just 9 percent of all R&D performed in the country, and 1994, when it performed almost 13 percent of all U.S. R&D. (See figure 5-1.) By 1997, the sector's performance share had dipped to just below an estimated 12 percent.

Character of Work

Academic R&D activities are concentrated at the research (basic and applied) end of the R&D spectrum and do not in-

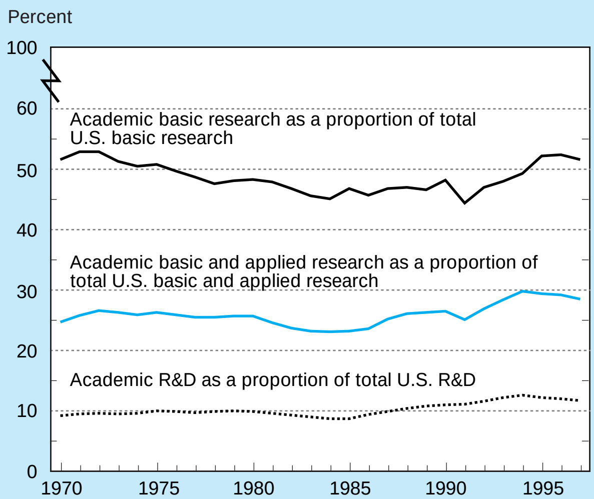
[2]Data in this section come from several different National Science Foundation surveys; these do not always use comparable definitions or methodologies. NSF's three main surveys involving academic R&D are (1) the Federal Funds for Research and Development Survey; (2) the Federal Support to Universities, Colleges, and Selected Nonprofit Institutions Survey; and (3) the Scientific and Engineering Expenditures at Universities and Colleges Survey. The results from this last are based on data obtained directly from universities and colleges; the former two surveys collect data from federal agencies. For descriptions of the methodologies of these and other NSF surveys, see NSF (1995b and 1995c). Federally funded research and development centers associated with universities are tallied separately and are examined in greater detail in chapter 4.

[3]This discussion is based on data in NSF (1996b) and unpublished tabulations. For more information on national R&D expenditures, see chapter 4, "National R&D Spending Patterns."

[4]Academic institutions generally comprise institutions of higher education that grant doctorates in science or engineering and/or spend at least $50,000 for separately budgeted R&D.

[5]Notwithstanding this delineation, the term "R&D"—rather than just "research"—is used throughout this discussion unless otherwise indicated, since almost all of the data collected on academic R&D do not differentiate between "R" and "D." Moreover, it is often difficult to make clear distinctions among basic research, applied research, and development. For the definitions used in NSF resource surveys, see chapter 4.

Figure 5-1.
Academic R&D, research, and basic research as a proportion of U.S. totals

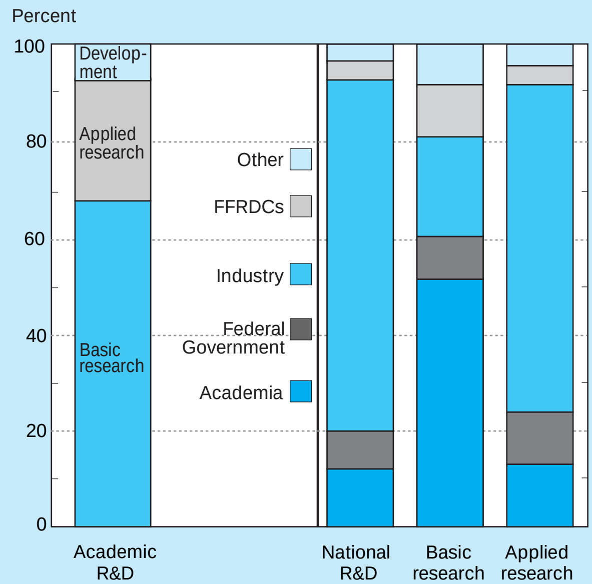


NOTE: Data for 1996 and 1997 are estimates.

See appendix tables 4-4, 4-5, and 4-6.

Science & Engineering Indicators – 1998

Figure 5-2.
National and academic R&D expenditures, by character of work and performer: 1997



NOTE: Data are estimates. FFRDCs are federally funded research and development centers.

See appendix tables 4-4, 4-5, 4-6, and 5-1.

Science & Engineering Indicators – 1998

clude much development activity.[5] Of 1997 academic *R&D* expenditures, an estimated 67 percent went for basic research, 25 percent for applied research, and 8 percent for development. (See figure 5-2.) From a national *research*—as opposed to national R&D—perspective, academic institutions accounted for between 23 and 30 percent of the U.S. total during the past three decades. In terms of *basic research* alone, the academic sector is the country's largest performer, accounting for between 44 and 53 percent of the national total during the past three decades. (See figure 5-1.)

Growth

Average annual R&D growth between 1984 and 1994 (in constant 1992 dollars) was much stronger for the academic sector than for any other R&D-performing sector—5.7 percent, compared to about 4.2 percent for other nonprofit laboratories, 1.5 percent for industrial laboratories, 0.6 percent for federally funded research and development centers (FFRDCs), and zero growth for federal laboratories. Since 1994, this growth has slowed to an estimated 1.6 percent annually; however, this rate is still higher than for any other R&D-performing sector but industry (which grew at an estimated 6.2 percent annually). As a proportion of gross domestic product (GDP), academic R&D rose from 0.23 to 0.30 percent between 1984 and 1997.

Funding Sources

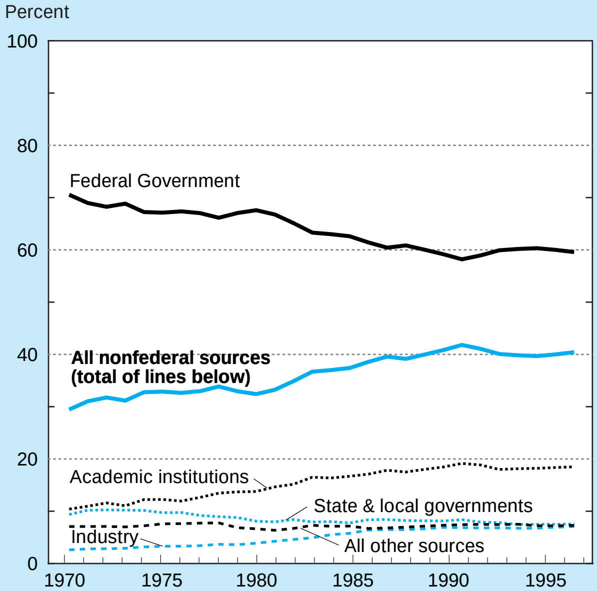
The Federal Government continues to provide the majority of funds for academic R&D. In 1997, it accounted for an estimated 60 percent of the funding for R&D performed in academic institutions. Nevertheless, the federal support share is declining fairly steadily, down from 68 percent in 1980 and 71 percent in 1970. (See figure 5-3.) Until the beginning of the 1990s, support from other sectors grew more rapidly than did that from the Federal Government. This trend reversed in the early 1990s, with federal support growing faster than nonfederal through 1995. Federal support is estimated to grow more slowly than nonfederal in both 1996 and 1997. The federal sector primarily supports basic research—71 percent of its 1997 funding went to basic research versus 20 percent to applied. Nonfederal sources provide a larger share of their support for applied research (61 percent for basic and 32 percent for applied research).

Federal support of academic R&D is discussed in detail later in this section; the following summarizes the contributions of other sectors to academic R&D.[6]

- **Institutional funds.** Institutional funds are separately budgeted funds that an academic institution spends on R&D from unrestricted sources, unreimbursed indirect costs associated with externally funded R&D projects, and mandatory and voluntary cost sharing on federal and other

[6] The academic R&D funding reported here only includes separately budgeted R&D and institutions' estimates of unreimbursed indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing. It does not include departmental research, and thus will exclude funds—notably for faculty salaries—in cases where research activities are not separately budgeted.

Figure 5-3.
Sources of academic R&D funding



NOTE: Data for 1996 and 1997 are estimates.

See appendix table 5-2. *Science & Engineering Indicators – 1998*

grants. These constitute the second largest source of academic R&D funding. The share of support represented by institutional funds has been increasing fairly steadily since 1980, save for a brief downturn in 1992 and 1993. In 1980, institutional funds accounted for about 14 percent of all academic R&D expenditures; the estimated 1997 share is about 19 percent.[7] The major sources of institutional R&D funds are (1) general-purpose state or local government appropriations, particularly for public institutions; (2) general-purpose grants from industry, foundations, or other outside sources; (3) tuition and fees; (4) endowment income; and (5) gifts that are not restricted by the donor to research. Other potential sources of institutional funds are income from patents or licenses and income from patient care revenues. (See "Income From Patenting and Licensing Arrangements" later in this chapter; also see "Academic Research and the Changing U.S. Health Care System" for a discussion of how the level and nature of research at medical schools may be affected by changes in the U.S. health care system.)

♦ **State and local government funds.** The share of academic R&D funding provided by state and local governments fluctuated slightly around the 8 percent level between 1980 and 1991, and declined steadily to just above 7 percent in 1994 before beginning a (slight) increase back up toward an estimated 8 percent in 1997. This share, however, only reflects funds directly targeted to academic R&D activities and does not include general-purpose state or local government appropriations that are used for separately budgeted research or to cover unreimbursed indirect costs. Consequently, the actual contribution of state and local governments to academic R&D is understated, particularly for public institutions.

♦ **Industry funds.** The funds provided for academic R&D by the industrial sector, although they account for the smallest share of funding, grew faster than did funding from any other source during the past two decades. Industry increased its share from slightly below 3 percent in 1970, to about 4 percent in 1980 and about 7 percent in 1990, where it has since remained. Industry's contribution to academia represented an estimated 1.3 percent of all industry-funded R&D in 1997, compared to 0.8 percent in 1980 and 0.6 percent in 1970. In the past two years, however, this relative contribution has declined slightly from its peak of 1.5 percent in 1994. "Industry-University Ties and the Conduct and Dissemination of Academic Research" touches on some of the concerns raised by industry funding of academic R&D, particularly its impact on the nature of university research and the dissemination of research findings.

♦ **Other sources of funds.** Other sources of support include grants for R&D from nonprofit organizations and voluntary health agencies and gifts from private individuals that are restricted by the donor to research, as well as all other sources restricted to research purposes not included in the other categories. Since 1986, this source of academic R&D support has stayed fairly constant at about 7 percent.

Funding by Institution Type

Patterns of sectoral funding of academic R&D vary depending on the type of academic institution involved. That is, the importance of different funding sources varies for both private and public universities. (See appendix table 5-3.) For all *public* academic institutions combined, just under 10 percent of R&D funding in 1995—the most recent year for which data are available—came from state and local funds, about 23 percent from institutional funds, and about 54 percent from the Federal Government. *Private* academic institutions received about 2 percent of funds from state and local governments, 9 percent from institutional sources, and 73 percent from the Federal Government. Both public and private institutions received approximately 7 percent of their respective R&D support from industry in 1995. Over the past two decades, the federal share of support has declined, and the industry and institutional shares have increased, for both public and private institutions.

[7]Some of the growth in institutional R&D funds may be due to accounting changes, including both a shift of departmental research to separately budgeted research and increased institutional ability to calculate unreimbursed indirect costs, including mandatory and voluntary cost sharing. Available data suggest, however, that it is unlikely that this accounts for the bulk of the increase. Growth in institutional R&D funds has been roughly in line with growth in academic institutions' total operating expenditures over the past two decades. Growth has also been steady over the entire time period, without the sudden shifts that would be expected if better or significantly different reporting were to occur simultaneously in a large number of institutions.

Academic Research and the Changing U.S. Health Care System

Clinical revenues generated by medical school faculty have traditionally been used to support undergraduate and graduate medical education and research at U.S. medical schools. These revenues are also thought to be a major source of support for younger researchers, who often have difficulty obtaining external grants. In a study for the American Association of Medical Colleges Task Force on Medical School Financing (Jones and Sanderson 1996), it is estimated that clinical revenues generated by medical school faculty to support core academic programs totaled $2.4 billion in 1993. The major beneficiary of this support ($816 million) was found to be research, followed by undergraduate medical education ($702 million) and graduate medical education ($594 million). Jones and Sanderson note that hospitals may also provide clinical support for academic missions by applying hospital funds to academic programs and by absorbing academic program expenses that are not otherwise reimbursed. However, changes in the U.S. health care system—particularly the emergence of managed care, the growing consolidation of health care providers, and increased price competition—are believed to be adversely affecting both the level and nature of research at medical schools. For example, two recent studies (Moy et al. 1997; and Campbell, Weissman, and Blumenthal 1997) suggest that faculty members at U.S. medical schools might be conducting less clinical research because of pressure on their institutions to cut costs and raise revenues. They show that in regions where managed care plans are dominant and where there is stiff competition for dollars and patients among hospitals, physicians at academic medical centers report more pressure to take care of patients—and thus conduct fewer human studies, do less clinical research, and publish fewer papers.

The main finding of the Moy study is that medical schools in all markets had comparable rates of growth in NIH awards from 1986 to 1990, but that between 1990 and 1995, medical schools in markets with high managed care penetration had slower growth in the dollar amount and number of awards compared with schools in markets with medium or low managed care penetration. The authors conclude that their results "provide evidence of an inverse relationship between growth in NIH awards during the last decade and managed care penetration among U.S. medical schools," although they do state that it remains to be determined whether the association is causal. One of the findings of the Campbell study is that clinical researchers in less competitive health care markets published more scientific articles than those in more competitive health care markets. Another finding is that a significantly larger proportion of young faculty members had patient care duties in more competitive markets than in less competitive markets. The authors conclude that "increased competitiveness of health care markets seems to hinder the capacity of academic health centers to conduct clinical research and to foster the careers of young clinical faculty."

These findings raise questions as to where the funds for clinical research that might be lost due to the changing health care market are to come from in the future, as well as the patients to participate in clinical research experiments.

Distribution of R&D Funds Across Academic Institutions[8]

Most academic R&D is now, and has been historically, concentrated in relatively few of the approximately 3,600 higher education institutions in the United States.[9] In fact, if all such institutions were ranked by their 1995 R&D expenditures, the top 200 institutions would account for about 94 percent of R&D expenditures. In 1995:

- the top 10 institutions spent 17 percent of total academic R&D funds ($3.7 billion),
- the top 20 institutions spent 29 percent ($6.5 billion),
- the top 50 spent 55 percent ($12.10 billion), and
- the top 100 spent 78 percent ($17.2 billion).[10]

This historic concentration of funds, however, has diminished somewhat during the past decade. In 1985, the top 10 institutions received about 19 percent of the funds. The decline in this group's share is approximately matched by the increase in the share of those institutions in the group below the top 100—this group's share increased from 19 to 22 percent of total academic R&D funds. The institutions ranked from 11 to 100 received similar shares in 1995 as in 1985 (between 61 and 62 percent). (See appendix table 5-4.)

[8]The Carnegie Foundation for the Advancement of Teaching classified about 3,600 degree-granting institutions as higher education institutions in 1994. (See chapter 2, "Characteristics of U.S. Higher Education Institutions," for a brief description of the Carnegie categories.) These higher education institutions include four-year colleges and universities, two-year community and junior colleges, and specialized schools such as medical and law schools. Not included in this classification scheme are more than 7,000 other postsecondary institutions (secretarial schools, auto repair schools, etc.).

[9]See Geiger and Feller (1995) for an interpretation of the patterns of dispersion of academic research funds among universities.

[10]These percentages exclude the Applied Physics Laboratory (APL) at the Johns Hopkins University. With an estimated $447 million in total expenditures and $434 million in federally financed expenditures in fiscal year 1995, APL performs about 57 percent of the university's R&D. Although not officially classified as an FFRDC, APL essentially functions as one. Its exclusion therefore provides a better measure of the distribution of academic R&D dollars and the ranking of individual institutions.

Expenditures by Field and Funding Source[11]

The overwhelming share of academic R&D expenditures in 1995 went to the life sciences, which accounted for 55 percent of total academic R&D expenditures, 53 percent of federal academic R&D expenditures, and 57 percent of nonfederal academic R&D expenditures. Within the life sciences, medical sciences accounted for 27 percent of total academic R&D expenditures and biological sciences for 17 percent. The next largest block of total academic R&D expenditures was for engineering—16 percent in 1995. (See appendix table 5-5; for detailed data on expenditures over time by S&E field, see appendix table 5-6.)

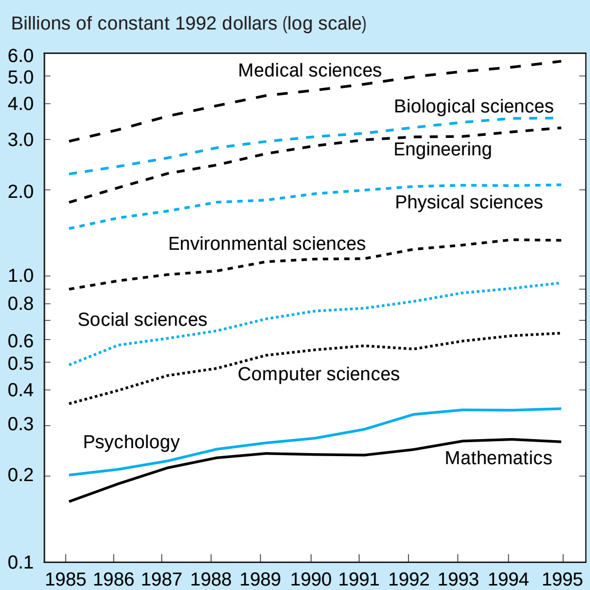
Between 1985 and 1995, academic R&D expenditures for all fields combined grew at an average annual rate of 5.2 percent in constant 1992 dollars. (See figure 5-4.) Funding for the social sciences grew fastest during the decade, increasing at an average annual rate of 6.8 percent in constant dollars. Within the social sciences, political science was the fastest growing fine field (8.1 percent) and economics the slowest growing (4.2 percent). Engineering grew second fastest, increasing at an average annual rate of 6.2 percent. Within engineering, aeronautical/astronomical and civil engineering grew the fastest (7.5 percent and 7.4 percent, respectively) and electrical engineering the slowest (5.5 percent). Academic R&D expenditure growth was slowest in the physical sciences, averaging 3.6 percent. Within the physical sciences, physics and chemistry grew the slowest (2.5 percent and 2.9 percent, respectively) and astronomy the fastest (8.8 percent). All other S&E fields averaged rates of annual growth between 4 and 6 percent.

The distribution of federal and nonfederal funding of academic R&D in 1995 varied by field. (See appendix table 5-5.) For example, the Federal Government supported about 78 percent of academic R&D expenditures in both physics and atmospheric sciences, but only 32 percent of academic R&D in economics and 30 percent in the agricultural sciences.

The declining federal share in support of academic R&D is not limited to particular S&E disciplines. Rather, the federally financed fraction of support for *each* S&E field was lower in 1995 than in 1975. (See appendix table 5-7.) The most dramatic decline occurred in the social sciences (55 percent in 1975 to 39 percent in 1993); the smallest declines were in the computer sciences and environmental sciences (74 to 70 percent and 71 to 67 percent, respectively). The overall decline in federal share also holds for all the reported S&E fine fields except the agricultural sciences (which increased slightly from 29 to 30 percent). Many fields have experienced slight increases in federal share during the first half of the 1990s.

[11]The data in this section are drawn from NSF's Scientific and Engineering Expenditures at Universities and Colleges Survey. For various methodological reasons, parallel data by field from the NSF Survey of Federal Obligations to Universities and Colleges do not necessarily match these numbers.

Figure 5-4.
Academic R&D expenditures, by field



NOTE: See appendix table 4-1 for GDP implicit price deflators used to convert current dollars to constant 1992 dollars.

See appendix table 5-6. *Science & Engineering Indicators – 1998*

Federal Support of Academic R&D

Top Agency Supporters

Federal obligations for academic R&D are concentrated in three agencies: the National Institutes of Health, the National Science Foundation, and the Department of Defense. Together, these agencies are estimated to have provided approximately 82 percent of total federal financing of academic R&D in 1997, as follows:

- NIH—57 percent,
- NSF—15 percent, and
- DOD—10 percent.

An additional 14 percent of the 1997 obligations for academic R&D are provided by the National Aeronautics and Space Administration (NASA, 6 percent); the Department of Energy (DOE, 5 percent); and the Department of Agriculture (USDA, 3 percent). (See appendix table 5-8.) Federal obligations for academic research are concentrated similarly to those for R&D. (See appendix table 5-9.)There are some differences, however, since some agencies place greater emphasis on development (DOD), while others place greater emphasis on research (NSF).

During the 1990s, NASA's funding of academic R&D increased most rapidly, with an estimated average annual growth rate of 3.1 percent per year in constant 1992 dollars. The next highest rates of growth were experienced by NIH (2.7 percent) and NSF (1.9 percent). Between 1996 and 1997, total federal obligations for federal R&D are estimated to decline in constant dollars. Only NSF (by 3 percent) and DOE

Industry-University Ties and the Conduct and Dissemination of Academic Research

Growing industry support of academic R&D and expanding industry-university ties have given rise to two concerns: that universities' commitment to basic research may be undermined, and that free and open disclosure of academic research results may face restrictions. In a chapter in *Challenge to the Research University*, Wesley M. Cohen and coauthors Richard Florida, Lucien Randazzese, and John Walsh (1998) examine these issues in light of recent research. Key hypotheses and research results are summarized here.

A number of indicators suggest that industry-university research relations have indeed expanded substantially since the mid-1970s. The industry share of academic R&D has more than doubled during that time. In 1990, 1,056 university-industry R&D centers—nearly 60 percent of them established during the 1980s—spent $2.9 billion on R&D. Patenting at the top 100 research universities expanded from 177 awards in 1974 to 1,486 in 1994; 200 offices administered technology transfer and licensing activities in 1990, compared with 25 in 1980. The authors also cite anecdotal evidence of an increase in spinoffs or faculty participation in new firms, along with increasing equity shares held by universities in firms spun off to commercialize academic research outputs.

Different incentives motivate firms and universities to form these partnerships. University initiatives led to the establishment of almost three-quarters of the university-industry research centers—61 percent originating with faculty, 12 percent with administrators.

The authors hypothesize that firms' profit incentive may incline them to control access to results of research they have sponsored and that it may also focus them on applied rather than basic research. This conflicts with academics' priority—the free and open publication and dissemination of their research findings, which is the source of academic eminence and the basis for further scientific inquiry. Thus, widespread industry-university collaborations may induce shifts toward more applied academic research and restricted disclosure of academic research findings. Others have suggested that firms may shift some of their internal fundamental research to academia.

Cohen, Florida, Randazzese, and Walsh provide some evidence for their hypotheses. On the issue of restricted access to research results, 53 percent of a national sample of university-industry research centers allowed firms to request publication delays; 35 percent permitted deleting of information prior to submission for publication (Cohen, Florida, and Goe 1994). For 117 centers whose missions most strongly supported an orientation toward industry needs, these numbers were higher: publication delays, 63 percent; deletion of information, 54 percent. Moreover, study respondents reported restrictions on faculty communications with faculty and staff at the home university (21 percent), with those at other universities (29 percent), and with the general public (42 percent). These numbers are about 15 percentage points higher for centers strongly oriented toward industry needs. Cohen, Florida, Randazzese, and Walsh note, however, that although publication and communications restrictions may be contained in agreements, they are not necessarily always implemented. They also indicate that implementation of such restrictions may undermine key channels through which academic research affects industrial R&D.

Similarly, in a sample of companies supporting academic life science research, 82 percent stipulated that research results could be kept confidential pending a patent application; 47 percent had agreements permitting at least occasional embargo of results beyond the patent application (Blumenthal et al. 1996). In a survey of academic technology managers, 39 percent reported having agreements that placed restrictions on faculty sharing information regarding R&D breakthroughs with departmental or other center faculty. In that study, 79 percent of the technology managers and 53 percent of faculty with experience in interacting with firms indicated that firms had asked for R&D results to be delayed or kept from publication (Rahm 1995). Cohen, Florida, Randazzese, and Walsh note that the existence of spinoff companies raises the same set of questions and speculate that similar pressures may apply to the composition and disclosure of research—the main difference being that they would be generated by the faculty, rather than externally.

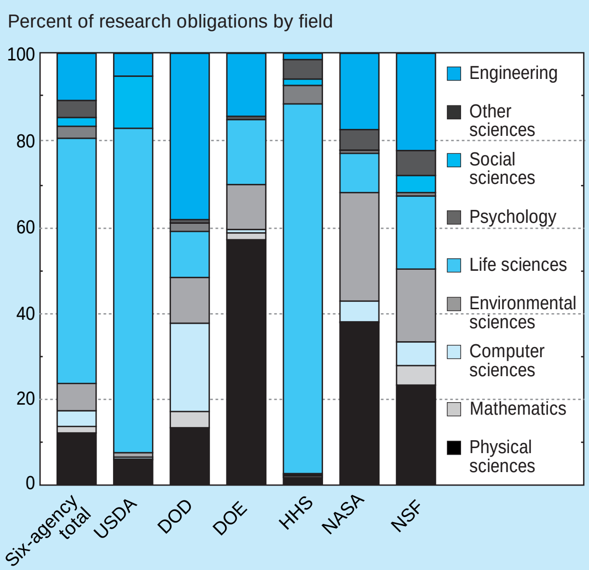
The evidence regarding a displacement of basic by applied research is less clear. Several studies have found an empirical association between greater faculty-industry interaction and more applied research (Rahm 1994, Morgan 1993 and 1994); another survey found that stronger center mission focus on improving industry activities was associated with lower shares of center effort going toward basic research (Cohen, Florida, and Goe 1994). However, while acknowledging the difficulty of drawing a boundary between basic and applied research, Cohen, Florida, Randazzese, and Walsh note that university-reported NSF data on the composition of academic R&D fail to reflect a shift away from basic research, which constituted 67 percent of academic R&D during 1980-83 and 66 percent during 1990-93. They point out that industry support may be attracting faculty already inclined toward applied research, rather than inducing others to shift away from basic research.

(by 0.5 percent) are expected to increase their academic R&D obligations in 1997.

Agency Support by Field

Federal agencies emphasize different S&E fields in their funding of academic research. Several agencies concentrate their funding in one field—the Department of Health and Human Services (HHS) and USDA focus on the life sciences, while DOE concentrates on the physical sciences. Other agencies—NSF, NASA, and DOD—have more diversified funding patterns. (See figure 5-5.) Even though an agency may place a large share of its funds in one field, it may not be an important contributor to that field, particularly if it doesn't spend much on academic research. (See figure 5-6.) NSF is the lead funding agency in the physical sciences (34 percent of total funding), mathematics (53 percent), and the environmental sciences (47 percent). DOD is the lead funding agency in the computer sciences (60 percent) and in engineering (38 percent). HHS is the lead funding agency in the life sciences (85 percent), the social sciences (41 percent), and psychology (86 percent). Within S&E fine fields, other agencies take the leading role—DOE in physics (46 percent), USDA in agricultural sciences (99 percent) and economics (75 percent), and NASA in astronomy (68 percent) and in both aeronautical (60 percent) and astronautical (64 percent) engineering.

Figure 5-5.
Distribution of federal agency academic research obligations, by field: FY 1995



USDA = Department of Agriculture; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation

NOTE: The six agencies reported represent approximately 96 percent of federal academic research obligations.

See appendix table 5-10. *Science & Engineering Indicators – 1998*

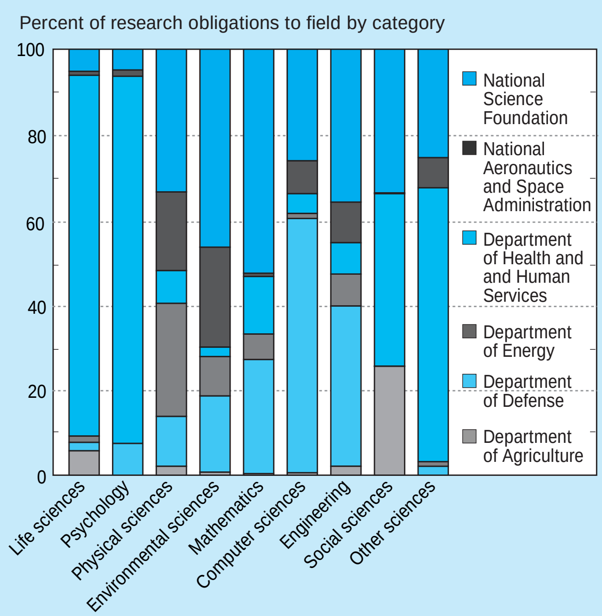
The Spreading Institutional Base of Federally Funded Academic R&D[12]

Despite fluctuations over the past couple of decades, the number of academic institutions receiving federal support for their R&D activities has increased, rising from 555 in 1975, to 648 in 1985, and to 882 in 1995.[13] (See text table 5-1.) Since most research and doctorate-granting institutions were already receiving federal support in 1975, almost the entire increase has occurred among comprehensive; liberal arts; two-year community, junior, and technical; and professional and other specialized schools. The number of such institutions receiving federal support has just about doubled over the 1975-95 period, rising from 335 in 1975, to 422 in 1985, and to 654 in 1995. These institutions are also receiving a larger share of the reported federal obligations for R&D to universities and colleges now than in the past—11 percent in 1995, compared to 7 percent in 1985.

[12]The data in this section are drawn from NSF's Federal Support to Universities, Colleges, and Selected Nonprofit Institutions Survey. The survey collects data on federal R&D obligations to individual U.S. universities and colleges from the 15 federal agencies that account for virtually all such obligations. For various methodological reasons, data reported in this survey do not necessarily match those reported in the Scientific and Engineering Expenditures at Universities and Colleges Survey.

[13]See NSB (1993) for a more comprehensive discussion of the spreading institutional base, which includes developments in individual S&E fields. The field analysis cannot be extended after 1993 because DOD no longer provides detailed academic R&D funding by field.

Figure 5-6.
Major agency field shares of federal academic research obligations: FY 1995



NOTE: The six agencies reported represent approximately 96 percent of federal academic research obligations.

See appendix table 5-11. *Science & Engineering Indicators – 1998*

Text table 5-1.
Number of academic institutions receiving federal R&D support

	All academic institutions	Research and doctorate-granting institutions[a]	Other institutions[a]
1975	555	220	335
1985	648	226	422
1990	746	227	519
1994	890	227	663
1995	882	228	654

[a]These are the institutional categories used by the Carnegie Foundation for the Advancement of Teaching. See chapter 2, "Characteristics of U.S. Higher Education Institutions," for information on these categories. "Other institutions" are all Carnegie-classified institutions except research and doctorate-granting institutions.

SOURCES: National Science Foundation, Science Resources Studies Division, *Federal Support to Universities, Colleges, and Nonprofit Institutions, Fiscal Year 1995,* Detailed Statistical Tables, forthcoming (Arlington, VA: 1998); and unpublished tabulations.

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Recently, legislation has been passed that requires federal agencies to demonstrate the impact of their programs. See "GPRA: Instituting Accountability in Federal Funding of Academic R&D" for a discussion of how this legislation hopes to improve federal planning and management, increase accountability for and assessment of results, and provide better information for congressional and agency decisionmaking.

Academic R&D Facilities and Instrumentation[14]

Facilities Overview[15]

Total Space. Between 1988-89 and 1996-97, total academic science and engineering research space increased by almost 22 percent, from about 112 million to 136 million net assignable square feet (NASF).[16] (See appendix table 5-12.) Planned construction expenditures for academic research facilities are expected to reach $3.1 billion (in constant dollars) in 1996-97.[17] If this planned funding materializes, it will reverse the recent downward trend that began between 1990-91 and 1992-93. Construction expenditures in constant dollars peaked at around $3.4 billion in 1990-91, dropped to $3.0 billion in 1992-93, and dropped again to $2.8 billion in 1994-95. (See appendix table 5-13.)

New Construction. New construction projects initiated between 1986 and 1995 were expected to produce over 52 million square feet of research space when completed—the equivalent of about 39 percent of estimated existing research space. A significant portion of this new research space likely replaces obsolete or inadequate space rather than actually increases existing space: this is indicated by the fact that the total amount of research space increased by 24 million NASF between 1988-89 and 1996-97, while new construction initiated between 1988-89 and 1994-95 was expected to increase by 43 million NASF. Planned new construction projects initiated in 1996-97 are expected to produce just under 11 million square feet of new research space. (See appendix table 5-12.)

Repair and Renovation. Planned expenditures for major repair/renovation (i.e., projects costing over $100,000) of academic research facilities are expected to reach $1.3 billion (in constant dollars) in 1996-97. These expenditures also increased between 1992-93 and 1994-95, rising from $905 million to $1.1 billion in constant dollars. (See appendix table 5-13.) While expenditures for major repair/renovation increased between 1992-93 and 1994-95, expenditures for smaller S&E research facility repair/renovation projects (those costing less than $100,000) decreased—dropping during this period from $261 million to $135 million in constant dollars. Projects initiated between 1986 and 1995 were expected to result in the repair/renovation of over 55 million square feet of research space.[18] Planned projects initiated in 1996-97 are expected to result in the repair/renovation of an additional 13.7 million square feet of research space. (See appendix table 5-12.)

Repair/renovation expenditures as a proportion of total capital expenditures (construction and repair/renovation) have increased steadily since 1990-91, rising from 25 percent of all capital project spending to 30 percent by 1994-95. Forty-three percent of all research-performing colleges and universities are planning to undertake some type of repair/renovation costing over $100,000 during 1996-97; 29 percent are planning to undertake construction projects during the same period.

Sources of Funds. Since 1986, there have been some shifts in the significance of various funding sources for the construction and repair/renovation of S&E research space. While the relative rankings of these sources have remained fairly

[14]Data on facilities and instrumentation are taken primarily from several NSF-supported surveys. Although terms are defined specifically in each survey, in general facilities expenditures (1) are classified as "capital" funds, (2) are fixed items such as buildings, (3) often cost millions of dollars, and (4) are not included within R&D expenditures as reported here. Equipment and instruments (the terms are used interchangeably) are generally movable, purchased with current funds, and included within R&D expenditures. Because the categories are not mutually exclusive, some large instrumentation systems could be classified as either facilities or equipment.

[15]The information in this section is derived from NSF's biennial Survey of Scientific and Engineering Research Facilities at Universities and Colleges. For more detailed data and analysis on academic S&E research facilities (for example, by institution type and control), see NSF (1996c).

[16]"Research space" here refers to the net assignable square footage of space within facilities (buildings) in which S&E research activities take place. Multipurpose space within those facilities, such as an office, is prorated to reflect the proportion of use devoted to research activities. NASF data are reported for combined years (e.g., 1987-88 data are for fiscal years 1987 and 1988.

[17]Current dollars have been adjusted to 1995 constant dollars using the U.S. Bureau of the Census's Composite Fixed-Weighted Price Index for Construction.

[18]It is difficult to report repaired/renovated space in terms of a percentage of existing research space. As collected, the data do not differentiate between repair and renovation, nor do they provide an actual count of unique square footage that has been repaired or renovated. Thus, any proportional presentation might include double or triple counts, since the same space could be repaired (especially) or renovated several times.

GPRA: Instituting Accountability in Federal Funding of Academic R&D

In response to the Clinton Administration's effort to move toward a government that works better and costs less, Congress passed the Government Performance and Results Act of 1993 (GPRA). GPRA aims to shift the focus of federal agencies away from traditional concerns such as staffing and the level of services provided and toward *results*. Specifically, GPRA looks to improve federal planning and management, increase accountability for and assessment of results, and provide better information for congressional and agency decisionmaking. To accomplish these and related goals, GPRA requires every federal agency to prepare detailed, multiyear strategic plans; annual performance plans; and annual performance reports. These documents give agencies formal tools with which to set forth goals, prepare plans to meet those goals, and to assess and measure progress and accomplishments on a regular and systematic basis.

GPRA poses a particular challenge for those agencies that must assess the scientific research programs they fund. In fact, the General Accounting Office (GAO) has found that measuring the discrete contribution of a federal initiative to a specific program result is particularly challenging for regulatory programs; scientific research programs; and programs that deliver services to taxpayers through third parties, such as state and local governments (U.S. GAO 1997a). Regarding research programs, GAO points out that the amount of money spent on R&D has been used as the primary indicator of how much research is being performed in a given area, but that such an *input* indicator does not provide a good indication of the *outcomes* (results) of the research. In a recent report, GAO notes that:

> …experts in research measurement have tried for years to develop indicators that would provide a measure of the results of R&D. However, the very nature of the innovative process makes measuring the performance of science-related projects difficult. For example, a wide range of factors determine if and when a particular R&D project will result in commercial or other benefits. It can also take many years for a research project to achieve results…Experiences from pilot efforts made under the Government Performance and Results Act have reinforced the finding that output measures are highly specific to the management and mission of each federal agency and that no single indicator exists to measure the results of the research (U.S. GAO 1997b).

The Subcommittee on Research of the Committee on Fundamental Science, which operates within the President's Office of Science and Technology Policy, has been working with federal research agencies to establish a broad framework for GPRA implementation in the assessment of fundamental science programs. The subcommittee states that:

> The central issue in assessing fundamental science lies in defining the goal against which progress is measured. The Administration's science policy statement, "Science in the National Interest" [Clinton and Gore 1994], establishes that goal as leadership across the frontiers of scientific knowledge. This is the critical measure for assuring that American scientists are expanding the knowledge base at the leading edge…
>
> Leadership evaluation does not entail simplistic numerical ranking of national programs. Our national interest in leadership rests in having our research and educational programs perform at the cutting edge—sometimes in competition, but often in explicit collaboration, with scientists from other nations. This goal is the principal guideline for government stewardship of science in the national interest. It is an enabling or intermediate objective with respect to the over-arching goals of improved health and environment, national security, economic prosperity, and quality of life . . . Science drives progress toward the over-arching national goals over a long time period and only as part of a larger enterprise requiring a complex interplay of science and technological innovation with fiscal, regulatory, intellectual property rights, and trade policies. Consequently, the enabling goal of maintaining broad scientific leadership is that which guides the management and assessment of today's science investments. It provides the principal yardstick for GPRA assessment strategies for fundamental science programs (NSTC 1996).

The subcommittee concludes that retrospective evaluation will have to be the main assessment tool and that it will have to be updated periodically to examine the link between fundamental science and the overarching national goals. A final concern related to GPRA's implementation in an R&D environment is that it may cause science agencies to focus on processes and process issues and to set inflexible process goals. Such an approach is likely to interfere with the conduct of research, which must be flexible and changeable to be effective.

Agencies are still struggling with GPRA's requirements in this arena, puzzling over how to balance the need for planning with the need for flexibility; the need for short-term measures with the reality of accomplishments that will only be realized in the long term. Despite these challenges, GPRA is an important requirement and can be an opportunity for government agencies, Congress, and the university community to better communicate to the public the value of investments in R&D and education.

constant—with state and local governments providing the largest share of support, followed by institutional funds—the proportions of funding for which they account have changed, sometimes dramatically. Most strikingly, the proportion of funds provided through private donations has declined. In 1986-87, this source accounted for about 20 percent of construction and repair/renovation funding; by 1994-95, however, its share had declined to about 12 percent. This reflects a drop in private donations to public institutions. Also of note, other debt grew from a 0.2 percent share in 1986-87 to account for 5.9 percent of funds in 1994-95; this reflects the increased importance of this funding source to private institutions. During the period, funds from federal sources[19] and from tax-exempt bonds first grew in significance—the former increasing from 6 percent in 1986-87 to about 14 percent in both 1990-91 and 1992-93, and the latter from just below 16 percent to about 21 percent in 1990-91—and then dropped to account for smaller overall shares in 1994-95 (about 8 and 13 percent, respectively). (See appendix table 5-14.)

In general, the major sources of funds for new construction are not the same as those for repair/renovation. About 43 percent of the funds for new construction come from state and local governments, with about 16 percent from institutional funds. The significance of these funding sources is reversed for repair/renovation. About 41 percent of the funds for repair/renovation come from institutional funds, and 25 percent from state and local funds. The proportion of repair/renovation funds from the Federal Government increased from 6 percent in 1988-89 to slightly above 10 percent in 1994-95, while the federal proportion for new construction decreased from 14 to 8 percent during the same period. (See appendix table 5-14.)

Public and private institutions draw upon substantially different sources to fund the construction and repair/renovation of research space. (See figure 5-7.) Public institutions rely primarily on:

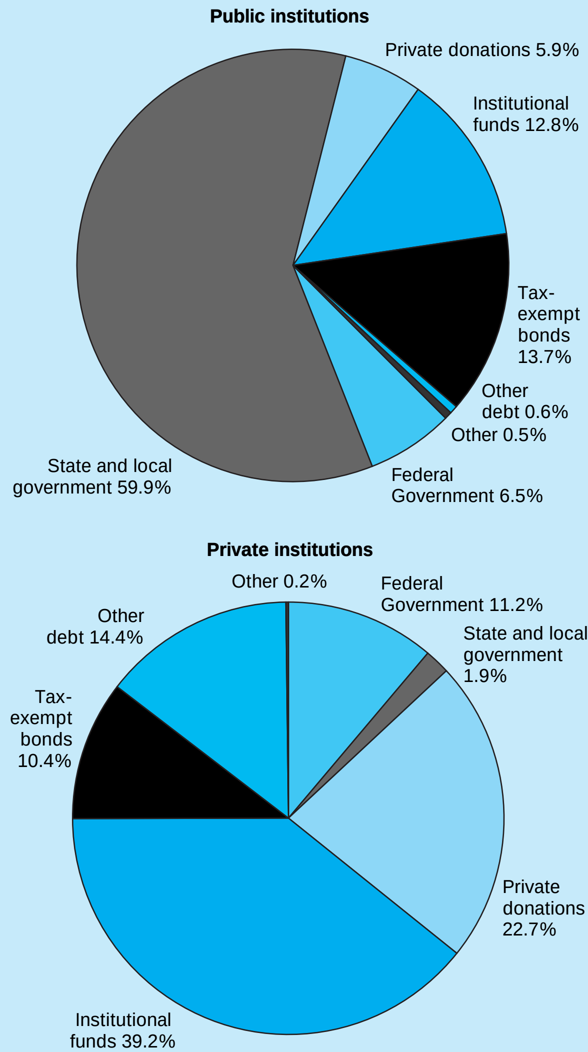
- ♦ state and local funding, which accounted for 46 percent of their total funding in 1992-93 and 60 percent in 1994-95;
- ♦ tax-exempt bonds, which accounted for 18 percent of their total funding in 1992-93 and 14 percent in 1994-95; and
- ♦ institutional funds, which accounted for 14 percent of their total funding in 1992-93 and 13 percent in 1994-95.

The Federal Government share declined from just above 14 percent in 1992-93 to below 7 percent in 1994-95.

Private institutions, for their part, rely primarily on:

- ♦ institutional funds, which accounted for 32 percent of their total funding in 1992-93 and 39 percent in 1994-95; and

Figure 5-7.
Funding sources for new construction and repair/renovation of S&E research space, by type of institution: 1994-95



See appendix table 5-14.

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- ♦ private donations, which accounted for about 18 percent of their total funding in 1992-93 and 23 percent in 1994-95.

A significant shift in the importance of tax-exempt bonds as a funding source for private institutions occurred between 1992-93—when they accounted for about 23 percent of total funding—and 1994-95, when they dropped to only about 10 percent. The decline in the importance of tax-exempt bonds over this period was roughly offset by an increase in the share of other debt from about 4 percent to about 14 percent. (See appendix table 5-14.)

Condition and Adequacy. Reported data suggest little change in the condition of academic S&E research space be-

[19]The actual amount of federal funds devoted to construction and repair/renovation is likely to be underrepresented because substantial federal funding for this purpose is received as overhead on federal grants and contracts. These funds are counted as institutional funds and may be used for construction and repair/renovation of research facilities.

Text table 5-2.
Condition of academic science and engineering research facilities
(Percentages)

<table>
<tr><th>Assessed condition of academic institutions' research space</th><th>1988</th><th>1990</th><th>1992</th><th>1994</th><th>1996[a]</th></tr>
<tr><td>Suitable for use in most scientifically sophisticated research</td><td>23.9</td><td>25.9</td><td>26.8</td><td>26.4</td><td rowspan="2">37.2</td></tr>
<tr><td>Effective for most uses, but not most scientifically sophisticated</td><td>36.8</td><td>35.3</td><td>34.7</td><td>32.8</td></tr>
<tr><td>Requires limited repair/renovation to be used effectively</td><td>23.5</td><td>23.3</td><td>22.6</td><td>23.1</td><td>43.9</td></tr>
<tr><td>Requires major repair/renovation to be used effectively[b]</td><td>15.8</td><td>15.5</td><td>12.8</td><td>12.9</td><td rowspan="2">18.5</td></tr>
<tr><td>Requires replacement[c]</td><td>NA</td><td>NA</td><td>3.1</td><td>4.1</td></tr>
</table>

NA = not available

NOTE: Percentages may not total 100 because of rounding.

[a]In 1996, the survey response categories were changed to: "suitable for the most scientifically competitive research"; "effective for most levels of research, but may need limited repair/renovation"; and "requires major renovation or replacement to be used effectively."

[b]The data for 1988 and 1990 in this category include space requiring replacement.

[c]This category was first used in the 1992 survey.

See appendix table 5-15.

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tween 1988 and 1994.[20] (See text table 5-2.) Specifically, about a quarter of this space was rated as suitable for use in the most scientifically sophisticated research; about a third was judged to be effective for most uses, but not most scientifically sophisticated; less than a quarter was reported as needing limited repair/renovation; and about a sixth was said to require major repair/renovation or replacement.

The 1996 survey responses cannot be readily compared to these earlier results because the wording and response choices have been changed. Specifically, the number of response categories has been reduced from five to three: suitable for the most scientifically competitive research; effective for most levels of research, but may need limited repair/renovation; and requires major renovation or replacement to be used effectively. This change essentially resulted in a shifting of about one-third of the space characterized in 1994 as "effective for most uses, but not most scientifically sophisticated," to the new category "suitable for the most scientifically competitive research"; and the other two-thirds to the new category "effective for most levels of research, but may need limited repair/renovation."

Unmet Needs. Determining what universities and colleges need with regard to S&E research space is a complex matter. In order to measure real as opposed to speculative needs, the 1994 facilities survey adopted a new approach to this issue. Faculty respondents were asked to report whether an approved institutional plan existed that included any deferred space needing new construction or repair/renovation.[21] Respondents were then asked to estimate, for each S&E field, the costs of such construction and repair/renovation projects. The 1996 survey expanded on this question by asking institutions to report separately the construction and repair/renovation costs for projects included in such plans, as well as for projects not included.

In 1994, a total of 40 percent of all research-performing universities and colleges had an approved institutional plan that included construction or repair/renovation projects that were either deferred and unfunded.[22] The estimated cost of these projects in constant dollars was $6.2 billion: $4.4 billion for new construction and $1.8 billion for repair/renovation. In 1996, 44 percent of research-performing institutions reported having an approved institutional plan that included construction or repair/renovation projects that were needed but that had to be deferred because funds were not available. These plans cited $7.4 billion of deferred capital project expenditures in constant dollars—$4.6 billion for new construction and $2.8 billion for repair/renovation. This total represents a $1.2 billion increase in deferred capital project costs between 1994 and 1996, the majority for repair/renovation ($970 million) and the remainder in deferred construction costs ($259 million). Another 11 percent of research-performing institutions identified $1.9 billion of needed deferred capital project expenditures that were not included in an institutional plan—$1.0 billion for new construction and $0.9 billion for repair/renovation.

Facilities by S&E Field

There was little change in the distribution of academic research space across S&E fields between 1988 and 1996. (See appendix table 5-12.) About 90 percent of current academic research space continues to be concentrated in six fields:

[20]Since the Survey of Scientific and Engineering Research Facilities at Universities and Colleges from which the results are derived is a sample survey, the small changes reported are not likely to be statistically significant.

[21]Four criteria were used to define deferred space in the 1994-95 survey: (1) the space must be necessary to meet the critical needs of current faculty or programs, (2) construction must not have been scheduled to begin during fiscal years 1994-95, (3) construction must not have funding set aside for it, and (4) the space must not be for developing new programs or expanding the number of faculty.

[22]The other 60 percent of the institutions surveyed might have needed new construction or repair/renovation but didn't have an approved institutional plan to that effect. Certain classes of institutions (smaller institutions, historically black colleges or universities) were less likely to have either a plan or a plan that includes deferred needs. Of those surveyed, the top 100 institutions in terms of research expenditures were most likely to have an approved institutional plan (60 percent), and the nondoctorate-granting institutions were least likely (26 percent).

- the biological sciences (21 percent in 1988 and 22 percent in 1996),
- the medical sciences (17 percent in 1988 and 18 percent in 1996),
- engineering (from 14 to 16 percent),
- the agricultural sciences (16 percent in both years),
- the physical sciences (from 14 to 13 percent), and
- the environmental sciences (from 6 to 5 percent).

The ratio of planned new construction during the 1986-95 period to existing research space differs across S&E fields.[23] More than half of the research space for medical sciences at medical schools and for computer sciences appears to have been built in the 1986-95 period. In contrast, less than 20 percent of the research space for mathematics and psychology appears to have been newly constructed during this period. (See figure 5-8.)

Condition and Adequacy. The condition of academic research space also differs across S&E fields. In 1996, the agricultural sciences reported the largest proportion among all S&E fields—about 24 percent—of research space in need of major repair/renovation or replacement. Other fields with higher than average needs for repair/renovation or replacement are the physical sciences (19 percent of total research space), the environmental sciences (19 percent), and the medical sciences both in universities and colleges (21 percent) and in medical schools (20 percent). In contrast, major repair/renovation or replacement was needed for only 13 percent of the total research space in the social sciences, 12 percent in psychology, 10 percent in mathematics, and less than 8 percent in the computer sciences. No particular trends have emerged as yet with respect to changes over time in repair/renovation needs across S&E fields. (See appendix table 5-15.)

In 1994, 40 percent or more of all institutions surveyed indicated inadequate amounts of research space in engineering, the physical sciences, the biological sciences outside of medical schools, and the medical sciences in medical schools. (See appendix table 5-16.) One-third or less of all institutions surveyed indicated inadequate amounts of S&E research space in the environmental sciences, the agricultural sciences, mathematics, psychology, and the social sciences. In 1996, 40 percent or more of all institutions indicated inadequate amounts of research space in all S&E fields except mathematics. More than half of all institutions indicated inadequate amounts of research space in engineering, the physical sciences, the biological sciences outside of medical schools, the medical sciences (both in and outside of medical schools), and the agricultural sciences. It is unclear how much of the change that occurred over the two periods is due to changes in the survey questionnaire rather than to an increasing inadequacy of research space.[24]

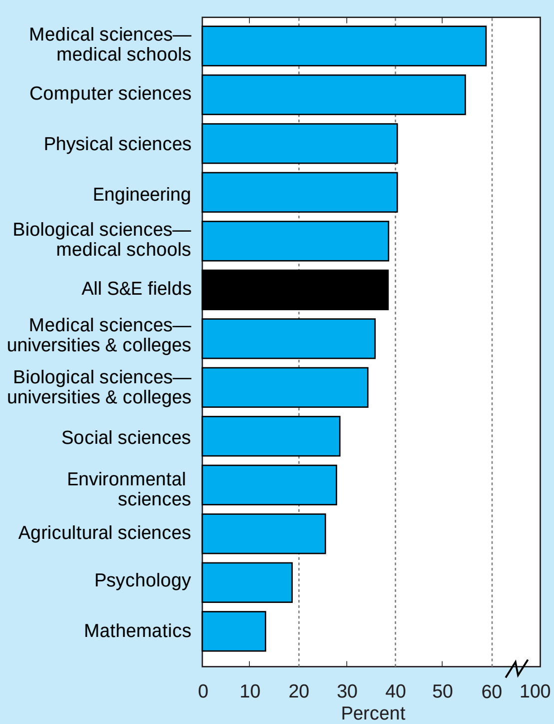
Unmet Needs. Deferred and unfunded needs existed in all S&E fields in 1996. The fields most frequently cited as having an unfunded need for new construction of research facilities as part of an institutional plan were the agricultural sciences (21 percent), engineering (19 percent), the medical sciences in medical schools (14 percent), and the physical sciences (13 percent). (See text table 5-3.) Unfunded need for repair/renovation projects reported in an institutional plan was indicated most strongly in the biological and medical sciences within medical schools (31 and 30 percent, respectively). An additional set of institutions reported deferred capital projects for both new construction and repair/renovation without an institutional plan in all S&E fields, with a larger percentage of institutions in each field reporting a need for repair/renovation projects than for new construction projects.

In four fields, estimated expenditures for needed capital projects (new construction plus repair/renovation) were over $1 billion (including those identified in an institutional plan or not in a plan): the physical sciences ($1.9 billion), engineering ($1.5 billion), the biological sciences outside of medical schools ($1.4 billion), and the medical sciences in medical schools ($1.3 billion). (See appendix table 5-17.)

[23]As noted earlier, the actual percentage of existing space that may have been repaired/renovated is not known because some space may have been repaired/renovated more than once.

[24]Again, the response choices were changed in 1996 compared to previous survey years. In 1994 and earlier, respondents were asked to rate the amount of research space in each field as either adequate, generally adequate, inadequate, nonexistent but needed, or not applicable or not needed. In 1996, these choices were narrowed down to three: adequate; inadequate, including insufficient; or not applicable or not needed.

Figure 5-8.
Percentage of S&E research space newly constructed between 1986 and 1995, by field: 1996



See appendix table 5-12. *Science & Engineering Indicators – 1998*

Text table 5-3.
Percentage of institutions with deferred capital projects to construct and/or repair/renovate S&E research facilities, by field, with and without an institutional plan: 1996

	Percentage of institutions[a]			
	With plan		Without plan	
Field	Construction	Repair/renovation	Construction	Repair/renovation
Physical sciences	13	22	3	12
Mathematics	2	10	3	6
Computer sciences	2	8	6	6
Environmental sciences	5	18	4	5
Agricultural sciences	22	19	11	14
Biological sciences				
Universities & colleges	10	17	5	14
Medical schools	10	32	3	10
Medical sciences				
Universities & colleges	10	13	6	12
Medical schools	14	30	3	12
Psychology	2	7	3	7
Social sciences	3	7	4	10
Engineering	21	26	4	9

[a]Percentage of all responding institutions with research space in the relevant S&E field.

SOURCE: National Science Foundation, Science Resources Studies Division, *Scientific and Engineering Research Facilities at Universities and Colleges: 1996,* NSF 96-326 (Arlington, VA: 1996).

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Instrumentation

Expenditures.[25] In 1995, just over $1.2 billion in current fund expenditures was spent for academic research instrumentation. Over 80 percent of these expenditures were concentrated in three fields: the life sciences (38 percent), engineering (23 percent), and the physical sciences (19 percent). (See figure 5-9.)

Between 1985 and 1995, current fund expenditures for academic research instrumentation first increased—growing at an average annual rate of 6.5 percent between 1985 and 1989—then dipped—dropping about 2 percent a year for the next four years—before recovering and growing by 3.6 percent from 1993 to 1994 and by 9.6 percent from 1994 to 1995 (in constant 1992 dollars). There were variations in growth patterns during this period among S&E fields. (See appendix table 5-18.)

Federal Funding. Federal funds for instrumentation are generally received either as part of research grants—thus enabling the research to be performed—or as separate instrumentation grants, depending on the funding policies of the particular federal agencies involved. The importance of federal funding for research instrumentation varies by field. In 1995, the social sciences received about 40 percent of their research equipment funds from the Federal Government. In contrast, federal support accounted for over 60 percent of instrumentation funding in the physical sciences, computer sciences, environmental sciences, psychology, and engineering.

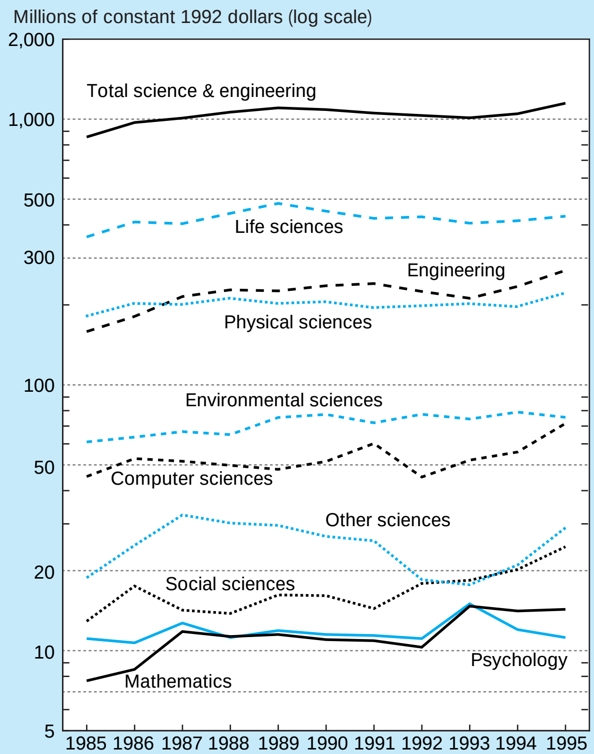
Since 1985, the share of research instrumentation expenditures funded by the Federal Government has declined—although not steadily—dropping from 64 to 59 percent. This overall pattern masks different trends in individual S&E fields. In one field—the environmental sciences—federal support actually rose, albeit very slightly, accounting for just below 68 percent of the field's instrumentation support in 1985 and just above 68 percent in 1995. Two other fields experienced sharp declines in federal support during this decade. The federal share for mathematics instrumentation dropped from 82 to 59 percent, and the share for computer sciences instrumentation dropped from 83 to 62 percent.

R&D Equipment Intensity. R&D equipment intensity is the percentage of total annual R&D expenditures from current funds devoted to research equipment. This proportion has declined since 1986, when research equipment accounted for 7.2 percent of total R&D expenditures. (See appendix table 5-19.) By 1993, R&D equipment intensity had dropped to 5.2 percent; it has since increased—slightly—to 5.6 percent in 1995.

R&D equipment intensity varies across S&E fields. It tends to be higher in the computer sciences (11.3 percent in 1995), physical sciences (10.6 percent), and engineering (8.2 percent); and lower in the social sciences (2.6 percent), psychology (3.3 percent), and life sciences (3.8 percent). This disparity is probably the result of the latter three fields using less equipment and/or less expensive

[25]Data used here are from the NSF Survey of Scientific and Engineering Expenditures at Universities and Colleges; they are limited to current funds expenditures for research instrumentation and do not include funds for instructional equipment. Current funds—as opposed to capital funds—are those in the yearly operating budget for ongoing activities. Generally, academic institutions keep separate accounts for current and capital funds.

Figure 5-9.
Current fund expenditures for research equipment at academic institutions, by field



NOTE: See appendix table 4-1 for GDP implicit price deflators used to convert current dollars to constant 1992 dollars.

See appendix table 5-18. *Science & Engineering Indicators – 1998*

instruments than the former three. Although the recent steady decline in R&D equipment intensity was not felt equally in all S&E fields, the 1986 figure was higher than that for 1995 in every field except mathematics. In that field, research equipment as a proportion of total R&D expenditures rose from 4.5 percent in 1986 to 5.4 percent in 1995. The data indicate, however, that the decline in R&D equipment intensity began to level off or reverse in 1993 for most S&E fields.

Stock, Condition, and Use. By congressional mandate, NSF has monitored academic research instrumentation status and needs since the early 1980s.[26] As of 1993 (the most recent year for which detailed instrumentation data are available), the 318 colleges, universities, and medical schools represented in the survey reported a combined estimated stock of 61,684 instruments, with an estimated aggregate original purchase price of $6.255 billion.[27] These instruments are categorized as shown in text table 5-4; their condition and usage were rated as follows:

- **Maintenance and repair.** Respondents rated 64 percent of the instruments as receiving above adequate to excellent maintenance/repair in 1993. Maintenance/repair was judged less than adequate or poor for only 8 percent of all instruments.
- **State-of-the-art status.** Overall, 27 percent of the instruments in research usage were rated as state of the art. An additional 63 percent were not state of the art, but were considered adequate for user needs. Only 9 percent were rated as inadequate.
- **Average age.** About 40 percent of the research instruments in use in 1993 had been acquired within the previous four years. Another 23 percent were over eight years old, and the average age of a research instrument was 5.8 years. (See appendix table 5-22.) Seventeen percent of all instruments costing under $1 million were less than two years old in 1993, but only 7 percent of instruments over $1 million were that new.
- **Use.** Sixty-four percent of the instruments reported in research use in 1993 were used exclusively for research. Most of the remainder (32 percent) were used predominantly for research with some instructional use. Only 4 percent of the total were used primarily for instruction with some research use.
- **Average number of users.** An average of 24.2 users per instrument was reported. Graduate students and postdoctorates assigned to the unit owning the instrument (i.e., the host unit) comprised the single largest category of user—an average of 8.5 per instrument. On average, there were also 3.5 faculty users from the host unit, 6.0 researchers from other units in the host institution, 4.5 researchers from outside the host institution, and 1.8 other users (primarily staff and undergraduates). In general—and not surprisingly—the higher an instrument's state-of-the-art ranking, the greater the number of researchers using it. For instance, an average of 25.7 researchers used the state-of-the-art instruments, while an average of 24.2 used the instruments that were not state of the art but that were adequate for their research. An average of 20.5 researchers worked with instruments that were rated as inadequate.

Needs. In the 1994 Instrumentation Survey, most (69 percent) of the responding heads of academic departments and research facilities reported that their research instrumentation needs had increased since the last survey in 1992. A slim majority—58 percent—were satisfied with the overall capability of their existing instrumentation to support their faculty's research interests. The remaining 42 percent rated their

[26]These data are collected via NSF's National Survey of Academic Research Instruments and Instrumentation Needs (Instrumentation Survey). NIH also provides funding for this survey. The survey consists of (1) questionnaires (now distributed every other year) that collect data on departmental equipment expenditures, equipment needs, and priorities; and (2) instrument data sheets (now distributed every four years) that collect detailed data from principal investigators on the condition, cost, usage, etc., of specific research instruments.

[27]For a more complete discussion of the characteristics of academic R&D instrumentation by S&E field, see NSF (1997b and 1998c).

Text table 5-4.
Research instrument stock, by category: 1993

Instrument category	Number	Cost (billion $)	Percentage of: Total stock	Percentage of: Total cost
Computers and data handling	12,023	1.85	19	30
Chromatographs and spectrometers	13,789	1.29	22	21
Microscopy	5,597	0.55	9	9
Bioanalytical	10,205	0.47	17	7
Other	20,071	2.10	33	34
Electronics and lasers	6,958	0.43	11	7
Major instrument systems[a]	1,295	0.64	6	10

NOTE: Cost reflects original purchase price.

[a]Major instrument systems include research vessels, telescopes, and other major instruments such as nuclear reactors, wind/wave/water/shock tunnels, and major prototype systems. See appendix table 5-22 for a complete breakdown.

SOURCE: National Science Foundation, Science Resources Studies Division, "Total Stock of Academic Research Instruments Tops $6 Billion in 1993," Data Brief, NSF 97-309 (Arlington, VA: 1997).

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research instrumentation as inadequate, and estimated the cost of the requisite upgrading at a total of $1.438 billion.

All respondents were asked to list and estimate the combined cost of the three top-priority research instruments costing over $20,000 their faculty most needed. Ten percent of the respondents said they had no immediate needs for additional instruments in this price range. For the others, the total combined cost of these items would be $2.048 billion, of which $942 million would be required for the top-priority item only. The primary reason cited for these top-priority research instruments was to upgrade unit capabilities—i.e., to perform experiments that the unit "cannot do now." The share from departments that reported inadequate overall instrumentation is an estimated cost of $939 million for their top three priority items—or about 65 percent of the $1.438 billion estimated cost to "fix" their units' overall instrumentation needs.[28]

Academic Doctoral Scientists and Engineers

This section examines major trends over the 1973-95 time period regarding the composition of the academic S&E workforce, its primary activities (teaching vis-à-vis research), and the extent of its support by the Federal Government. For a discussion of the nature of the data used here, see "Data Sources: Nature, Problems, and Comparability."

[28]For a more complete discussion of academic instrumentation needs by S&E field and by major instrument category and field, see NSF (1996a).

The Academic Doctoral S&E Workforce[29]

The total number of scientists and engineers in the U.S. labor force with doctoral degrees from U.S. universities has more than doubled over the past two decades, rising from about 215,000 in 1973 to 475,200 in 1995; the academic component increased from an estimated 118,000 to 217,500.[30] (See text table 5-5.) The rate of academic employment growth, though robust over much of the period, was lower than growth in other sectors. The growth rate for academic employment dropped from nearly 7 percent annually in the early 1970s to just under 1 percent from 1989 onward; consequently, the academic employment share declined from an estimated 55 percent in 1973 to 46 percent in the 1990s.

While the total number of academic doctoral scientists and engineers continued to rise from 206,700 in 1989 to 217,500 in 1995, the number of incumbents holding full-time faculty positions—full, associate, and assistant professors plus instructors—remained roughly stable at between 169,800 and 173,100. (See figure 5-10.) Consequently, the share of full-time faculty among all academic doctoral scientists and engineers declined to an all-time low of 79 percent. This drop continued a downtrend evident since the early

[29]The academic doctoral S&E workforce includes full, associate, and assistant professors and instructors—collectively defined throughout this section as faculty—lecturers, adjunct faculty, research and teaching associates, administrators, and postdoctorates.

[30]The trend data in this section refer to scientists and engineers with doctorates from U.S. institutions, regardless of their citizenship status. Comparable trend data for Ph.D.-level scientists and engineers with degrees from non-U.S. institutions are not available. A 1993 U.S. Department of Education survey of academic faculty suggests that this component of the academic workforce numbers around 13,000.

Text table 5-5.
Academic employment of doctoral scientists and engineers: Number, growth rate, and employment share

	Employment (thousands)		Average annual rate of change		Academic share of employment
	Total	Academia	Total	Academia	
1973	215.0	118.0			55
1975	250.8	134.1	8.02	6.60	53
1977	277.2	145.5	5.12	4.15	52
1979	306.7	155.4	5.19	3.35	51
1981	336.1	167.1	4.69	3.72	50
1983	363.1	176.2	3.93	2.68	49
1985	395.7	190.3	4.39	3.93	48
1987	416.5	196.0	2.60	1.48	47
1989	447.3	206.7	3.63	2.70	46
1991	468.6	210.6	2.36	0.92	45
1993	460.5	213.8	–0.87	0.75	46
1995	475.2	217.5	1.58	0.88	46

SOURCE: National Science Foundation, Science Resources Studies Division, Survey of Doctorate Recipients, unpublished tabulations.

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Data Sources: Nature, Problems, and Comparability

The data used in this section to describe the employment, characteristics, and activities of academic doctoral scientists and engineers derive mainly from the Survey of Doctorate Recipients (SDR) and in part from the National Study of Postsecondary Faculty (NSOPF).

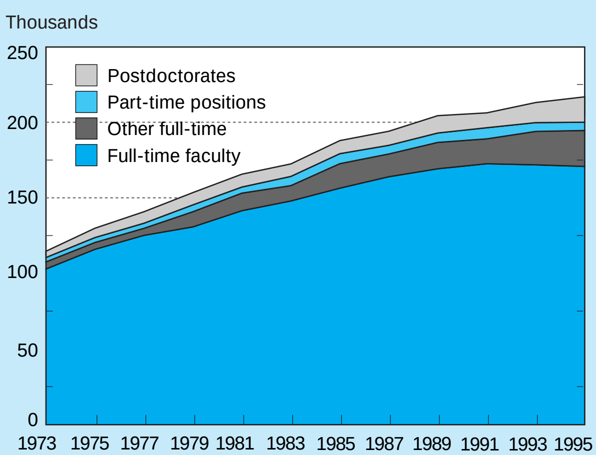
SDR is a sample survey conducted biennially since 1973 under the sponsorship of the National Science Foundation and several other federal agencies. The survey underwent several changes in 1991, and again from 1993 forward; these affect the comparability of data from these years with those of earlier periods. Through 1989, the sample included three major respondent segments: (1) recipients of S&E doctorates from U.S. institutions; (2) a small number of doctorate-holders in other fields who were working in S&E in the survey year; and (3) a small number of people with S&E doctorates from non-U.S. institutions.

Starting with the 1991 sample, only recipients of S&E doctorates from U.S. universities were retained, and persons over 75 years old were ruled out of scope. Further, sampling strata and sample size were reduced in an effort to improve response rates within budget constraints. Other changes in data collection also were introduced, most notably the use of computer-assisted telephone interviewing, which resulted in much higher response rates than had been attained previously. A 31-month interval elapsed between the 1989 and 1991 surveys instead of the usual 24 months; the interval between the 1991 and 1993 surveys was 20 months.

Methodological studies to assess the full impact of these changes on overall estimates and individual data items remain to be conducted. Preliminary investigations suggest that SDR data permit analysis of rough trends, provided comparisons are limited to recipients of S&E doctorates from U.S. institutions. This has been done herein, with data structured in accordance with suggestions offered by the National Research Council's Office of Scientific and Engineering Personnel, which has conducted all of these surveys through 1995. Nevertheless, in the text and tables presented here, apparently interesting but small statistical differences should be treated with caution.

NSOPF is a sample survey that was conducted by the U.S. Department of Education in 1988 and 1993. The two NSOPF survey frames are not comparable. Those with no teaching duties in the fall semester of 1988 were considered out of scope, while the comparable group was included in the 1993 cycle. Internally consistent subsets can be constructed and compared across the two survey years, however. Because the NSOPF estimates of doctoral scientists and engineers agree quite well with those derived from SDR, and since NSOPF contains information on teaching activities that is unavailable from SDR, data from this survey have been used to supplement SDR information.

Figure 5-10.
Academic doctoral scientists and engineers, by type of position



NOTE: Faculty positions include full, associate, and assistant professor and instructor.

See appendix table 5-23. *Science & Engineering Indicators – 1998*

1970s, when this share had stood at 88 percent. Psychology and the physical, environmental, and life sciences experienced particularly substantial shifts toward nonfaculty employment, with full-time faculty percentages dropping by 10 or more points. Developments in the social sciences, mathematics, and engineering were somewhat less pronounced. (See appendix table 5-23.)

The number of incumbents in other types of academic positions—full- and part-time adjunct faculty, lecturer, research and teaching associate, administrator, postdoctorate—grew at a more rapid rate than the number of full-time faculty, increasing from 14,700 in 1973 to 46,200 in 1995. The 1989-95 increase was 25 percent, in contrast to the essentially flat full-time faculty count. Most of the growth in this segment was due to postdoctorate[31] and other full-time appointments; part-time employees accounted for between 2 and 3 percent of the total throughout. (See appendix table 5-23.)

Employment growth was not uniform across different segments of higher education. Universities categorized as research universities in the Carnegie classification system experienced

[31]For more information on this subject, see "Postdoctoral Appointments" in chapters 2 and 3.

slower growth than other institutions;[32] their doctoral S&E staff increased by 56 percent, from 57,600 in 1973 to 90,100 in 1995. Other universities and colleges combined had twice that rate of increase, as their numbers went from 60,400 in 1973 to 127,400 in 1995. Consequently, the proportion of academic doctoral scientists and engineers employed by research universities dropped from 49 to 41 percent during the period. (See text table 5-6.)

Women in the Academic Doctoral S&E Workforce[33]

The number of academically employed women with S&E doctorates rose more than fourfold between 1973 and 1995, increasing from about 10,700 to an estimated 52,400. In comparison, the number of men increased by roughly 54 percent over the period, from 107,300 to 165,100. Consequently, men's employment share dropped by 15 percentage points, from 91 percent in 1973 to 76 percent in 1995. Women's gains were especially pronounced in psychology and the life and social sciences, fields where their participation in 1973 had already been the highest. (See appendix table 5-24.)

The recent decline in the full-time faculty component, discussed above, was driven by an estimated 10 percent drop in the number of male full professors since 1989—from 76,300 to 68,800—combined with roughly stable numbers of male associate professors and junior faculty (assistant professors and instructors). (See figure 5-11.) But the number of women serving as full professors, associate professors, and junior faculty—assistant professors and instructors—increased by 30 percent or more during this time. By 1995, women constituted 21 percent of full-time S&E faculty. The number of women also increased faster than the number of men—41 versus 17 percent since 1989—in the other types of academic positions: full- and part-time adjunct faculty, lecturer, research and teaching associate, administrative, and postdoctorate. (See appendix table 5-24.)

Throughout the period, the field distribution of women remained more concentrated than that of men. Fully 84 percent of women scientists and engineers in 1995 were found in three broad fields: life sciences (41 percent), social sciences (21 percent), and psychology (22 percent). In contrast, only 58 percent of men were in these fields in 1995. Conversely, only 8 percent of women, but 19 percent of men, were in the physical and environmental sciences; and just 3 percent of women were in engineering versus 14 percent of men. (See appendix table 5-24.)

These field distributions in academic employment reflect the different field patterns of doctorate degrees earned by men and women. Over the past two decades, increased hiring of women into academia has been commensurate with women's rising proportion of new S&E doctorates. Among

[32] This periodically revised classification describes research universities as institutions with a full range of baccalaureate programs, commitment to graduate education through the doctorate, annual award of at least 50 doctoral degrees, and receipt of federal support of at least $15.5 million (average of 1989 to 1991). See Carnegie Foundation for the Advancement of Teaching (1994).

[33] Also see chapter 3, "Women in the S&E Workforce."

Text table 5-6.
Academic doctoral scientists and engineers, by type of employing institution

	Thousands employed by:			Percentage employed by:	
	Academia (total)	Research universities	All other institutions	Research universities	All other institutions
1973 ...	118.0	57.6	60.4	49	51
1975 ...	134.1	63.3	70.8	47	53
1977 ...	145.5	67.7	77.8	47	53
1979 ...	155.4	71.3	84.1	46	54
1981 ...	167.1	78.5	88.6	47	53
1983 ...	176.2	77.2	99.1	44	56
1985 ...	190.3	85.5	104.8	45	55
1987 ...	196.0	91.3	104.7	47	53
1989 ...	206.7	93.8	112.9	45	55
1991 ...	210.6	93.5	117.1	44	56
1993 ...	213.8	92.8	120.9	43	57
1995 ...	217.5	90.1	127.4	41	59

NOTE: Institution types are based on the Carnegie Foundation for the Advancement of Teaching classification of higher education institutions.

SOURCE: National Science Foundation, Science Resources Studies Division, Survey of Doctorate Recipients, unpublished tabulations.

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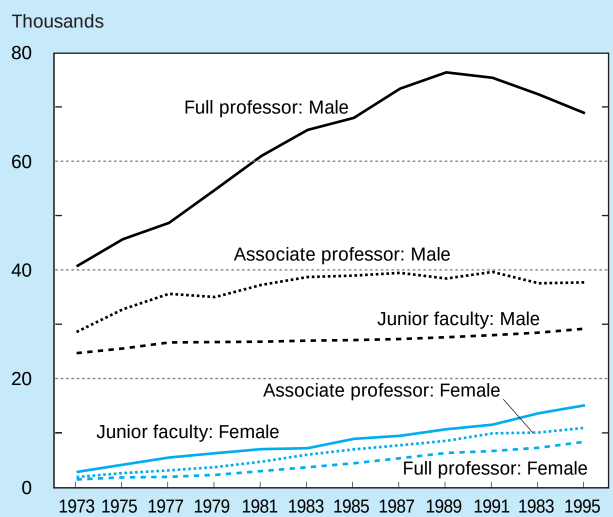
Figure 5-11.
Full-time doctoral S&E faculty, by rank and sex



NOTE: Faculty positions include full, associate, and assistant professors plus instructors. Junior faculty members are either assistant professors or instructors.

SOURCE: National Science Foundation, Survey of Doctorate Recipients, unpublished tabulations.

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recent Ph.D.s in academic employment,[34] women have been represented in rough proportion to their share of newly awarded doctorates in every major field over the entire 1973-95 period. However, their proportion of the doctoral academic S&E workforce—24 percent in 1995—continues to lag their percentage of new S&E doctorates—38 percent. (See text table 5-7.)

Underrepresented Minorities in the Academic Doctoral S&E Workforce[35]

Academic employment of underrepresented minorities—blacks, Hispanics, Native Americans, and Alaskan Natives[36]—rose to 12,800 in 1995 from 2,400 in 1973. Their employment share rose from 2 percent in 1973 to 6 percent in 1995, the same as their share of full-time faculty positions. Relative gains for underrepresented minorities were greatest in psychology and the social sciences—where their employment share rose from 2 to 8 percent—and in engineering—from 2 to 5 percent. (See appendix table 5-25.)

These low but rising numbers reflect the growing number of S&E Ph.D.s earned by members of underrepresented minorities.[37] For the past two decades, underrepresented minorities have been hired into academic positions at somewhat higher rates than would be expected based on their share of new S&E Ph.D.s awarded. As a consequence, their representation in the total academic workforce has been close to their share of new doctorates. (See text table 5-7.)

The distribution of underrepresented minorities by field is similar to that of whites, with two exceptions. Underrepresented minorities are *less* likely than whites to be in the life sciences—28 versus 34 percent, and they are *more* likely to be in psychology and the social sciences—41 versus 33 percent.

Asians in the Academic Doctoral S&E Workforce[38]

Asians as a group have been quite successful in entering the academic workforce. The number of Asian academic doctoral scientists and engineers rose rapidly between 1973 and 1995, increasing from 5,100 to 22,500 in 1995. This growth more than doubled their employment share: 10 percent in 1995 versus 4 percent in 1973. Asians made especially strong gains in the physical sciences (from 5 percent in 1973 to 14 percent in 1995), computer sciences (from 13 percent in 1985 to 29 percent in 1995),[39] and engineering

[34]Recent Ph.D.s are those who have earned their doctorates within the past three years.

[35]Also see chapter 3, “Racial/Ethnic Minorities in the S&E Workforce.”

[36]There is variation among and within these groups, which are treated here in the aggregate. Appendix table 5-25 provides somewhat more detailed data; the survey sample does not permit further disaggregation. Asians as a group have been quite successful in entering the academic workforce and are treated separately.

[37]This in turn, of course, reflects their increasing participation in higher education and graduate school training. See chapter 2, “Master’s Degrees by Race/Ethnicity” and “Doctoral Degrees by Race/Ethnicity.”

[38]Again, also see chapter 3, “Racial/Ethnic Minorities in the S&E Workforce.”

[39]Pre-1985 estimates are unreliable because of the low number of computer science degree-holders in the sample.

Text table 5-7.
Women, underrepresented minorities, and Asians in academic doctoral S&E employment

	Recent academic S&E Ph.D.s[a] (thousands)	Women as a percentage of:			Underrepresented minorities as a percentage of:[b]			Asians as a percentage of:		
		New S&E doctorates	Recent academic S&E Ph.D.s[a]	Total academic workforce	New S&E doctorates	Recent academic S&E Ph.D.s	Total academic workforce	New S&E doctorates	Recent academic S&E Ph.D.s[a]	Total academic workforce
1973	25.0	12	12	9	2	2	2	7	5	4
1975	23.4	16	17	10	3	4	2	6	7	5
1977	22.5	19	19	11	4	5	3	5	8	5
1979	20.9	22	21	12	5	5	3	6	8	6
1981	20.7	25	25	14	5	5	4	6	8	7
1983	20.5	28	28	15	5	5	4	5	10	7
1985	21.8	31	29	16	5	5	4	6	11	7
1987	21.1	32	29	17	6	6	4	6	12	8
1989	23.3	34	31	19	6	7	4	6	14	8
1991	25.5	36	35	20	6	7	5	7	16	8
1993	25.1	37	33	22	7	7	5	8	21	10
1995	26.9	38	38	24	7	7	6	15	23	10

[a]Recent academic S&E Ph.D.s are defined as those in academic positions at the time of survey who have earned their S&E degree in the preceding three years.

[b]Underrepresented minorities in S&E include black, Hispanic, Native American, and Alaskan Native respondents.

SOURCES: National Science Foundation, Science Resources Studies Division, Survey of Earned Doctorates and Survey of Doctorate Recipients, unpublished tabulations.

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(from 9 percent in 1973 to 21 percent in 1995). (See appendix table 5-25.)

Asians are increasingly prominent among new Ph.D.s in academia, well in excess of their share of S&E Ph.D.s awarded to U.S. citizens and permanent visa-holders. That is, Asians, more than any other group, tend toward academic employment. By 1995, Asians accounted for nearly one-quarter of all new academic S&E doctorates. (See text table 5-7.)

Fifty-four percent of Asian academic S&E doctorates are in the physical, environmental, and computer sciences; mathematics; or engineering—a much higher proportion than for whites (33 percent) or underrepresented minorities (32 percent). Few Asians enter psychology, and a relatively small proportion is in the social sciences. (See appendix table 5-25.)

Employment Growth by Field

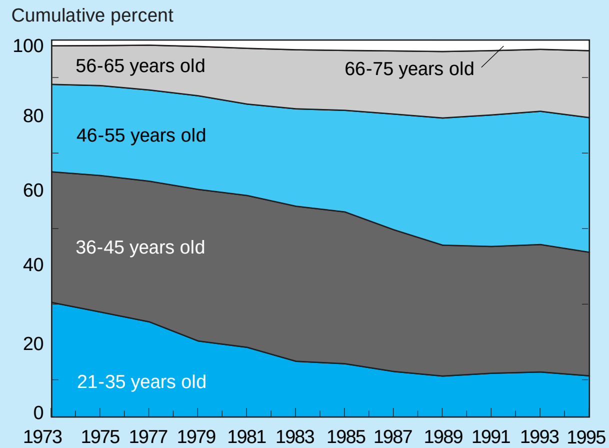
Academic employment in the physical sciences grew more slowly than in other fields over the 1973-95 period, rising from 22,100 to 29,300—33 percent growth compared to 84 percent for all of S&E combined. As a result, the share of academic doctoral scientists and engineers employed in the physical sciences fell from 19 to 13 percent; this drop was experienced in both physics and chemistry. In contrast, employment in the life sciences increased by more than 100 percent over the period, rising from 34,900 to 71,600; this field's employment share rose from 30 to 33 percent. Other fields experiencing relative gains were engineering and psychology. (See appendix tables 5-24 and 5-25.)

The Shifting Faculty Age Structure

The rapid pace of hiring of young Ph.D.s into academic faculty positions during the 1960s to accommodate soaring enrollments, combined with slower hiring in later years, resulted in an aging professoriate. (See figure 5-12.) Through the 1980s, a growing proportion of academic faculty was found in the older age brackets. A noteworthy feature of the data involves the upper end of these age distributions. The fraction of total faculty older than 65 has been about 3 percent for the past decade, with 1 percent older than 68 years. By and large, academics tend to retire before that age.

Concerns had been voiced early in the decade about the possible deleterious effects of delayed faculty retirements resulting from the full applicability of provisions of the Age Discrimination in Employment Act to universities and colleges starting in 1994.[40] The concerns focused on the potential ramifications for universities' organizational vitality, institutional flexibility, and financial health. A study by the National Research Council (NRC) concludes that "overall, only a small number of the nation's tenured faculty will continue working in their current positions past age 70" (NRC 1991, p. 29), but adds: "At some research universities a high proportion of faculty would choose to remain employed past age 70 if allowed to do so" (NRC 1991, p. 38).

Figure 5-12.
Age distribution of full-time doctoral S&E faculty



NOTE: Faculty positions include full, associate, and assistant professor and instructor.

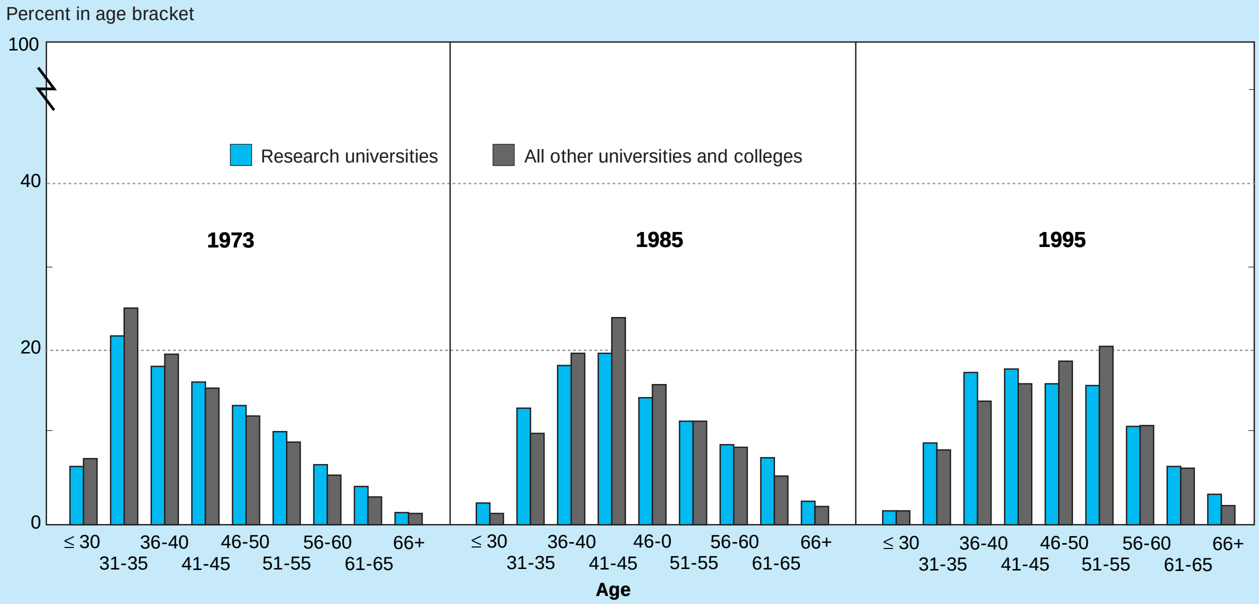
See appendix table 5-26. *Science & Engineering Indicators – 1998*

Recent data indicate, however, that, for the system as a whole, little has changed in the last decade in terms of retirement behavior. (See appendix table 5-27.) Across all of higher education, about 3 percent of full-time faculty stay on beyond age 65. As anticipated by the NRC study, faculty at research universities tend to keep working longer than those elsewhere. But it is also worth noting that research universities have managed to maintain a relatively more balanced age structure than other types of universities and colleges. (See appendix table 5-27.) The faculty age distribution in research universities tended to be older, on average, than that of other academic institutions through the early 1980s, but that tendency has since reversed. By 1995, research universities had a greater share of their full-time faculty in the under-46 age brackets than other institutions, and a slightly greater share in the above-60 ones as well. (See figure 5-13.)

The mean and median ages of full-time doctoral faculty show a clear upward trend from 1973 through 1989, with a flattening thereafter. (See figure 5-14.) This result can now be interpreted in light of the overall number of faculty, which grew through 1989 and has since essentially held steady in the range of 169,800 and 173,100. During the years of growth, the average faculty age climbed from 42.5 to 47.1 years before leveling off. This suggests that for academia as a whole—not necessarily for individual institutions or departments—a rough balance has been maintained between attrition from all causes and new hires. However, the number of replacements from 1989 onward has to be seen in the context of Ph.D. awards which rose by more than one-fifth overall from 1989 to 1995 (up from 22,705 to 27,846) and by 30 percent for U.S.

[40]A 1986 amendment to the Age Discrimination in Employment Act of 1967 prohibited mandatory retirement on the basis of age for almost all workers. Higher education institutions were granted an exemption through 1993, allowing termination of employees with unlimited tenure who had reached age 70.

Figure 5-13.
Age distribution of full-time doctoral S&E faculty at research universities and other academic institutions



NOTES: Faculty positions include full, associate, and assistant professor and instructor. Research universities are defined by 1994 Carnegie categories. See appendix table 5-27.

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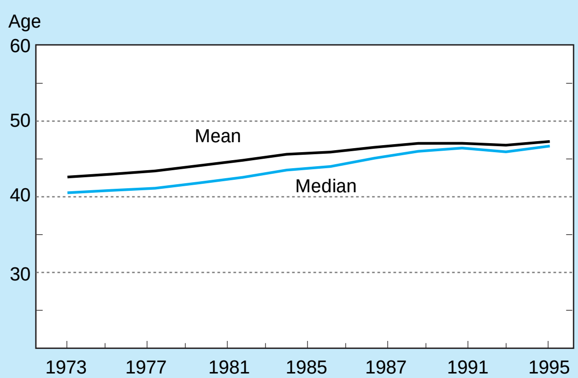
Figure 5-14.
Average age of full-time doctoral S&E faculty



NOTE: Faculty positions include full, associate, and assistant professor and instructor.

SOURCE: National Science Foundation, Science Resources Studies Division, Survey of Doctorate Recipients, unpublished tabulations.

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citizens and permanent residents. (This latter growth reflects in part Chinese students' conversion to permanent visa status following the Tiannanmen Square events.) In short, the modest increases in hiring from the late 1980s onward took place against a backdrop of steeply rising numbers of new Ph.D.s.

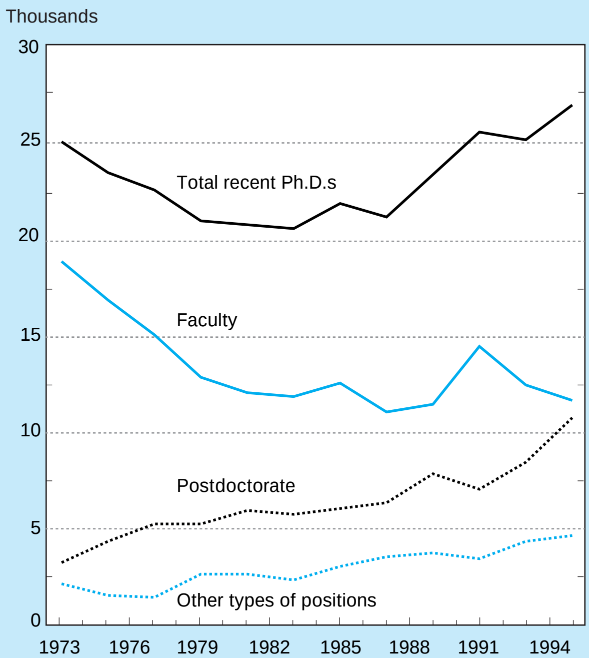
New Ph.D.s in Academic Employment[41]

The presence in academic employment of people with newly earned S&E doctorates provides a leading-edge indicator of the future composition of the academic teaching and research workforce. Because of the small number of new Ph.D. recipients entering academic employment relative to the size of the existing workforce, changes in the overall composition of the academic workforce will occur slowly—but are already visible, as noted above.

The number of recent Ph.D.s entering into academia—defined as those who had earned their doctorate in the three years preceding the survey—declined gradually from 25,000 in 1973 through the early 1980s, reaching a low of 20,500. It then rose again through the mid-1990s, reaching 26,900 in 1995. These represent just over half of all recent doctorate-holders. (See appendix table 5-28.) But the meaning of academic "employment" has changed for these young Ph.D.s. Fewer than 45 percent had regular faculty appointments in 1995, compared with over 75 percent in the early 1970s and 57 percent in the mid-1980s. (See figure 5-15.) Since 1973, the proportion of new doctorate recipients holding postdoctorate positions has increased steeply, rising from 13 to 28 percent in 1985 and 40

[41]No trend data exist on detailed in- and outflows. The data reported here are "snapshots" of the number and demographic characteristics of doctorate-holders in academic employment who had earned their degree in the three years preceding the survey.

Figure 5-15.
Number of recent Ph.D.s in academic S&E, by type of position



NOTES: Recent Ph.D.s are those who have earned their doctorate in the preceding three years. Faculty positions include full, associate, and assistant professor and instructor.

See appendix tables 5-29 and 5-30.

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percent in 1995.[42] The proportion of doctorates in other nonfaculty appointments has also doubled, rising from 8 to 17 percent. (See appendix table 5-30.)

The *demographic composition* of these recent academic doctorate-holders has shifted noticeably over two decades. The proportion of women has risen from 12 to 38 percent. The proportion of underrepresented minorities has grown from 2 to 7 percent, and of Asians from 5 to 23 percent. (See text table 5-7 and appendix table 5-30.) The *field composition* of young Ph.D.s reflects the larger employment changes: 38 percent are in the life sciences (up from 28 percent in 1973), 14 percent are in the physical sciences (after dropping from 16 in 1973 to 11 percent in 1985), and 4 percent are in mathematics (down from 9 percent in 1973). But the field distribution of young Ph.D. recipients in full-time faculty positions differs from this total employment picture, with smaller faculty shares in the physical and life sciences and higher fractions in psychology and the social sciences. (See appendix table 5-29.)

Research and Teaching Activities[43]

In the academic workplace, particularly in universities with a strong research orientation, teaching, research, and research training are often inextricably intertwined. In this way, academic research produces both new knowledge *and* highly trained personnel. Most academic scientists and engineers do not do *either* teaching or research, but pursue *both* activities in a mix that may change with the time of year and the course of their careers. Nevertheless, for the past two decades, a reasonably consistent indicator of the relative balance between teaching and research may be obtained from responses of academic doctoral scientists and engineers to a question about their major work responsibilities. The discussion here commences with an examination of a snapshot of the distribution of research and teaching activities, including undergraduate and graduate teaching, in academia; proceeds to trends in respondents' *primary* work responsibility; and closes by focusing on trends in primary and secondary responsibilities.

While not directly addressing the synergy between teaching and research, a survey (NSOPF) conducted by the U.S. Department of Education allows examination of the patterns of undergraduate and graduate teaching activities of doctoral academic scientists and engineers, and the extent of their research activities in relation to these teaching duties.

Of the estimated 213,800 doctoral scientists and engineers employed in academic institutions in 1993, 81 percent had some teaching duties in the fall semester of that year: 58 percent taught courses primarily for undergraduates, 25 percent taught courses primarily for graduate students, and 17 percent taught both graduate and undergraduate courses. (See text table 5-8.)

Those who taught undergraduate courses exclusively on average spent an estimated 65 percent of their weekly work time on teaching activities and 22 percent on research. For those with only graduate teaching responsibilities, the corresponding time estimates were 34 and 38 percent, respectively; and for those teaching both undergraduate and graduate

[42] An accurate count of postdoctorates is elusive, and the reported increase may be understated. A postdoctoral appointment is defined here as a temporary position awarded primarily for gaining additional training in research. The actual use of the term, however, varies among disciplines and sectors of employment. In academia, some universities appoint postdoctorates to junior faculty positions which carry fringe benefits; in others, the appointment may be as a research associate. Some postdoctorates thus may not regard themselves as genuinely "employed." Also see "Postdoctoral Appointments" in chapters 2 and 3.

[43] This material is based on individual respondents' reports of their primary and secondary work responsibilities. The data series—which is drawn from SDR—is reasonably consistent for the 1973-89 period: respondents were asked to designate primary and secondary work responsibilities from a list of items, the majority of which remained unchanged. Since 1991, however, primary and secondary work responsibilities have had to be inferred from reports of the activities on which respondents spent the most and second-most amount of their average weekly work time. These two methods yield close—but not identical—results, so the SDR series must be considered a rough indicator only. In addition, some nonrespondents in 1981-87 were sent a shortened version of the questionnaire that did not ask about secondary work responsibility. For these respondents and these years, secondary work responsibility was estimated using full-form responses, based on field and type of position held. This analysis also draws on data from the 1988 and 1993 NSOPF. As noted in "Data Sources: Nature, Problems, and Comparability," the sample estimates of numbers of faculty from this survey differ slightly from those derived from SDR.

Text table 5-8.
Teaching and research activities of academic doctoral scientists and engineers

Surveyed doctoral scientists & engineers	Thousands	Percentage	Average percentage of time spent on: Teaching	Research
1988 survey				
Total with teaching responsibilities[a]	176.1	100	50	27
Teaching undergraduates only	88.3	50	58	20
Teaching graduate students only	57.1	32	35	38
Teaching both	30.6	17	52	25
1993 survey				
Total with teaching responsibilities[a]	173.4	100	50	25
Teaching undergraduates only	100.0	58	65	22
Teaching graduate students only	43.9	25	34	38
Teaching both	29.6	17	50	27

NOTE: Total is based on all survey respondents with a doctorate in a science or engineering field.

[a]Data include all respondents who indicated that the number of students they taught was greater than zero.

SOURCE: U.S. Department of Education, National Survey of Postsecondary Faculty, 1988 and 1993; unpublished tabulations by the National Science Foundation.

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students, the percentages were 50 and 27. These time estimates have not changed greatly since 1988.[44]

Primary Work Responsibility: Emphasis on Research

SDR respondents (see "Data Sources: Nature, Problems, and Comparability") were asked to select their primary work responsibility from a list that includes teaching, various R&D functions, administrative work, consulting, and other activities. A crude but consistent indicator of the relative emphasis on research can be constructed from the responses. The choices in research activities as primary work responsibility reveal two major shifts. First, the relative balance between teaching and research has shifted toward the latter. Second, by this measure, growth of the research function has been especially pronounced outside the ranks of the traditional research universities.

The number of those reporting *teaching* as their primary work responsibility rose from 73,300 in 1973 to 101,100 in 1985 and has fluctuated around the 100,000 mark since then. In contrast, the number of those identifying *research* as their primary work responsibility has increased steadily, rising from 27,800 in 1973 to 56,000 in 1985 and 83,000 by 1995. These divergent trends have lowered the proportion of those reporting teaching as their primary work from 62 percent in 1973 to 46 percent in 1995, while the proportion of those reporting research as their primary work has risen from 24 to 38 percent. Those with other types of primary work responsibility—for administrative or managerial functions, service activities, and the like—constituted between 14 and 19 percent of the total over the period. (See appendix table 5-31.)

Employment growth in research universities since the late 1970s has been largely confined to those identifying research as their primary activity. Their number stood at 17,500 in 1973 and 45,900 in 1995, as their share rose from 30 to 51 percent of research universities' doctoral S&E workforce. In contrast, the number of research university faculty for whom teaching was the primary activity rose from 32,300 in 1973 to a high of 39,600 in 1981 before declining to 30,500 in 1995. The number identifying other functions as their primary work responsibility has remained at around 12,000 to 15,000 since the early 1980s. In other types of universities and colleges, a growing number of faculty identified teaching as their primary work activity for much of the two decades; since 1989, this number has fluctuated between roughly 67,000 and 70,000. But those for whom research was the primary work responsibility increased more rapidly and continuously. As their numbers grew from 10,300 in 1973 to 37,100 in 1995, their share rose from 17 to 29 percent. (See appendix table 5-31.)

Besides these institutional differences, there have been field differences as well. (See text table 5-9.) Employment growth from 1973 to 1995 has exceeded 50 percent in most fields,[45] except mathematics (41 percent) and—notably—the physical sciences (17 percent). Growth in *teaching* (as characterized here) was slower than overall employment growth in every field but the computer sciences; the physical sciences, by this measure, actually experienced negative growth. On the other hand, the number of respondents who designated *research* as their primary work responsibility

[44]Those without fall 1988 teaching responsibility were ruled out of scope in that survey year, but not in 1993. The comparison with 1988 is based only on those 1993 respondents with teaching responsibilities.

[45]Computer science data were not broken out before 1979. The series starts from a very low base and involves a relatively small number of respondents. Thus, the percentage increases in computer science teaching versus research growth must be viewed in this context and are best interpreted only within the field.

Text table 5-9.
Percentage change in the number of academic doctoral scientists and engineers by reported primary work responsibility, by field: 1973-95

		Percentage change in faculty (from 1973-95):		
Field	Total	Reporting teaching as primary	Reporting research as primary	Reporting other work as primary
Total science and engineering	66	32	186	91
Sciences	64	30	175	97
Physical sciences	17	–12	128	76
Environmental sciences	56	26	213	54
Mathematics	41	25	89	137
Computer sciences[a]	328	437	221	267
Life sciences	79	26	165	113
Psychology	85	49	237	108
Social sciences	72	53	235	62
Engineering	78	42	314	49

NOTE: Primary work responsibility is defined by respondent's designation from 1973 through 1989; after 1989, primary work responsibility is defined by respondent's designation of activity consuming the most work time.

[a]The very large percentage increases in this field are based on a very small number of degree-holders in 1981.

SOURCE: National Science Foundation, Science Resources Studies Division, Survey of Doctorate Recipients, unpublished tabulations.

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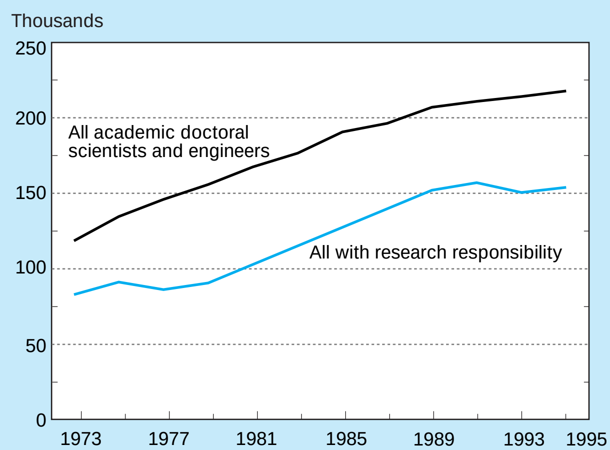
quadrupled in engineering and more than tripled in several science fields. In mathematics and the physical sciences, it roughly doubled.

Participation in Research

Academic work generally entails a more complex mix of functions—teaching, research, administrative work, consulting, public service, among others—than the above-discussed indicator (research as primary work activity) takes into account. A more encompassing measure can be constructed from respondents' choice of research as *either* a primary or secondary work function; this yields a better lower bound estimate of the broadly defined academic doctoral research workforce.[46] By this measure, an estimated 153,500 academic doctoral scientists and engineers were engaged in R&D in 1995, up from a range of 80,000 to 90,000 during the 1970s.[47] (See figure 5-16.) The number of academic researchers has essentially been stable since the late 1980s, after strong growth in the preceding decade and a half. (See appendix table 5-32.)

Roughly 71 percent of all academic doctoral scientists and engineers reporting primary and secondary work responsibilities in 1995 were engaged in research activities, but this varied by field. At the high end—80 percent—were the environmental sciences; the life and computer sciences and engineering ranged from 75 to 78 percent. Those in the physical sciences, mathematics, psychology, and the social sciences reported the lowest levels of research activity, ranging from 62 to 70 percent.

Figure 5-16.
Academic doctoral scientists and engineers and those with research responsibility



NOTES: Research responsibility is reported as primary or secondary responsibility for R&D. The numbers for 1981-85 are extrapolated, since not all respondents were asked about their secondary work responsibility in those years.

See appendix table 5-32. *Science & Engineering Indicators – 1998*

[46]The estimate fails to account for respondents who ranked research third or lower in their ordering of work responsibilities. Additionally, for 1981 through 1985, some respondents who received short forms of the survey questionnaire could not record a secondary work responsibility, thus resulting in a definite undercount for these years. All estimates are calculated based on individuals who provided valid responses to this item.

[47]A rough estimate of the nondoctoral researcher component, excluding graduate research assistants, was derived for 1993 from NSOPF. This study suggests that this component is approximately 10 percent the size of the doctoral research workforce and is concentrated in the medical and health sciences (60 percent), biological sciences (15 percent), and engineering (10 percent).

These field differences in the levels of research intensity have been fairly consistent over time, and the field composition of academic researchers has generally not shifted dramatically. But the relative employment shift noted earlier away from the physical sciences and toward the life sciences is evident in the research workforce as well. The physical science share has declined by 6 percentage points since 1973, and that of the life sciences has increased by 3 percentage points, with marginal gains or losses for the other fields. (See appendix table 5-32.)

Federal Support of Academic Researchers

In 1995, 39 percent of the academic doctoral scientists and engineers responding to SDR reported receiving funding from the Federal Government during the week of April 15. (See text table 5-10.) This number cannot be easily compared with those from earlier years, which were based on a year-long reference period—49 percent in 1989, 50 percent in 1991—but is in line with SDR estimates for other reference periods shorter than a full year: 37 percent each in 1985 and 1993. If the volume of academic research activity is not uniform over the entire academic year, but varies to accommodate teaching and other activities, a one-week or one-month reference period may well understate the extent of support over an entire academic year. Several pieces of evidence suggest this to be the case.[48]

[48]Indirect evidence that the extent of support is understated can be gleaned from the number of senior scientists and postdoctorates supported on NSF grants. This number is published annually as part of NSF's budget submission. It bears a relatively stable relationship to numbers derived from SDR in 1987, 1989, and 1991, but diverges sharply in 1993. (The figures from the two data sources are never identical, however, since NSF's numbers reflect those funded in a given fiscal year, while SDR numbers reflect those who have support from NSF regardless of when awarded.)

Just over half (51 percent) of the doctoral scientists and engineers surveyed in the 1993 NSOPF reported having Federal Government funding in the fall semester of that year. This is in line with earlier SDR estimates based on year-long reference periods. The NSOPF estimate, when taken together with information regarding growth in federal funding, suggests that no major changes have occurred since the late 1980s in the number or proportion of researchers supported with federal funds. This tentative conclusion is further bolstered by the steady growth in the number of federally funded research assistants through the 1980s and 1990s.

Notable and persistent field differences exist in the proportion of researchers supported by federal funds.[49] Above the overall S&E average are the life, environmental, and physical sciences and engineering. Clearly below the mean are mathematics, psychology, and the social sciences. The relative position of these fields has not changed substantially over the past two decades. (See text table 5-10.)

Since the late 1980s, a larger fraction of academic researchers has reported federal support from more than one agency. This trend can be observed across most S&E fields. (See appendix table 5-33.) Fields with the highest levels of researchers receiving multi-agency support are the environmental sciences—more than 40 percent—and engineering and the computer and physical sciences—well above 30 percent for each. Single-agency support is most prominent in the life and social sciences, psychology, and mathematics. However, no clear upward trend in multi-agency support is evident since the late 1980s.

[49]The relative field shares of federally supported researchers appear to be stable across recent survey years, i.e., they are relatively unaffected by changes in the survey reference period. The distribution (but not the estimated number) based on NSF estimates is quite similar.

Text table 5-10.
Percentage of academic doctoral scientists and engineers reporting federal R&D support, by field

Field	1973	1975	1977	1979	1981	1983	*1985*	1987	1989	1991	*1993*	*1995*
Total science and engineering	46	42	41	39	42	44	*37*	48	49	50	*37*	*39*
Sciences	45	41	40	38	41	43	*36*	47	48	49	*36*	*38*
Physical sciences	49	45	46	44	50	51	*43*	54	58	56	*46*	*48*
Environmental sciences	47	46	43	45	49	54	*51*	60	63	65	*51*	*54*
Mathematics	29	19	19	21	21	30	*21*	31	33	34	*19*	*22*
Computer sciences	NA	NA	NA	35	30	45	*45*	62	52	49	*40*	*43*
Life sciences	60	59	57	55	59	59	*53*	65	65	65	*52*	*52*
Psychology	39	36	33	32	32	30	*25*	31	35	35	*26*	*27*
Social sciences	26	24	23	20	21	24	*17*	27	28	28	*14*	*16*
Engineering	55	50	51	49	50	55	*42*	57	56	63	*43*	*50*

NA = not available

NOTES: Data are based on respondents who answered "yes" or "no" to a question on whether they received federal support. Data for 1985 (italicized), which specified a reference period of one month, and for 1993 and 1995 (also italicized), which specified a one-week reference period, are not comparable to data from other years. Due to the nature of academic research funding, percentages in these years will tend to understate the proportion with federal support during an entire academic year.

SOURCE: National Science Foundation, Science Resources Studies Division, Survey of Doctorate Recipients, unpublished tabulations.

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The interpretation of these data is ambiguous. They could, for example, indicate greater difficulty in obtaining funding, the growing availability of multiple funding sources, or increasing entrepreneurism by investigators in seeking out funding.

Integration of Research With Graduate Education

Science and engineering graduate students have a fairly unique role as both an input to and an output of the U.S. academic research system. U.S. research universities have traditionally coupled advanced education with research, both generating new knowledge and producing advanced scientific and engineering talent. This integration of research and advanced training in S&E is encouraged because the system has served the country well. U.S. research universities attract graduate students from across the nation and around the world. Upon receipt of their advanced degrees, these students set out to work in many sectors of the U.S. economy, using the skills and knowledge they have acquired to meet a broad range of challenges.

It is difficult to determine the exact number of S&E graduate students who are participating directly in the research process at their universities in a given year. Obviously, those students who are supported primarily through research assistantships are participating in research. Many of the students who are supported with other modes of support such as traineeships and fellowships are also likely to be directly involved in research activities at their institutions. And even students who are self-supported or are on teaching assistantships may be involved in research, at least part of the time. Any student who is working on a doctoral dissertation is expected to be doing research; in many cases, those working on master's theses are also expected to be doing research.

This section examines the sources and mechanisms of support for full-time S&E graduate students. Since the number of students supported by a research assistantship in any year is probably a lower bound for the number of S&E graduate students participating in research activities at U.S. universities, special emphasis is given to the role of the research assistantship. For a more in-depth treatment of graduate education, see chapter 2.

Support of S&E Graduate Students[50]

Trends in Support

In 1995, for the first time in almost two decades, enrollment of full-time S&E graduate students declined slightly. A 12-year trend of steady increases in enrollment of full-time graduate students whose primary source of support was the Federal Government also ended, as did an even longer upward trend in the number of graduate students whose primary source of support was from nonfederal sources.[51] The number of self-supported graduate students—that is, those whose largest source of support comes from loans or from personal or family financial contributions—also declined for the first time since 1988. (See appendix table 5-34.) It is too early to tell whether the 1995 enrollment decline is the beginning of a trend or simply a one-time drop. Preliminary evidence indicates, however, that this is not a one-time phenomenon, but rather part of a longer decline. For example, first-time enrollments of full-time S&E graduate students declined in both 1994 and 1995, and preliminary estimates from the 1996 Graduate Student Survey indicate that overall full-time enrollment dropped again in 1996.

Since 1980, there have been significant shifts in the relative usage of different types of primary support mechanisms. (See figure 5-17.) These shifts have been due more to rapid growth in some support mechanisms than to an absolute decline in the number of students supported by any of these mechanisms. In the past several years, concern has been voiced in a number of places about the value of different modes of support for S&E graduate students and whether the Federal Government and other providers of financial assistance should consider shifting the mix of their support (COSEPUP 1995 and NSF 1996d). For a summary of these discussions, see "Concern About Forms of Support for S&E Graduate Students."

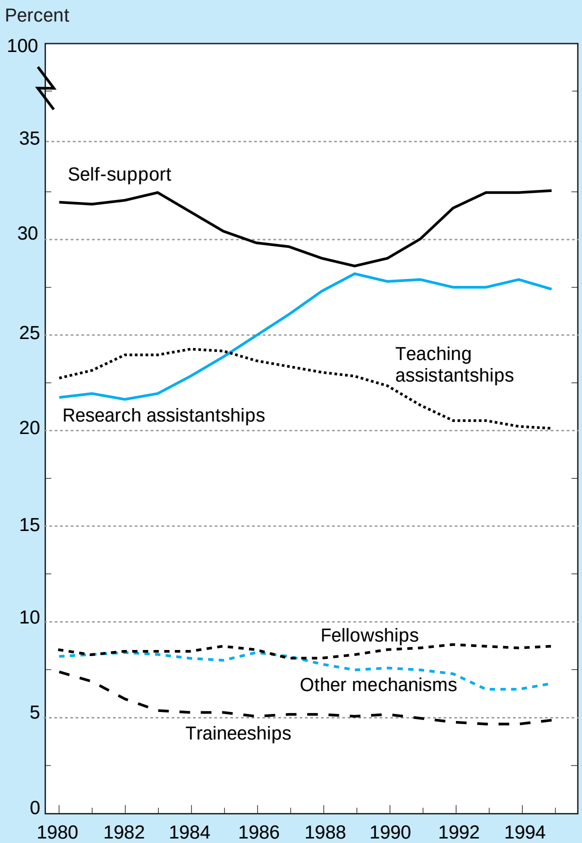
The proportion of graduate students with research assistantships as their primary support mechanism increased from 22 to 27 percent between 1980 and 1995. This increase was offset by a drop in the proportions of students supported by traineeships (from 7 to 5 percent) or by teaching assistantships (from 23 to 20 percent). Most of these changes had occurred by the late 1980s, with proportional shares being relatively stable during the first half of the 1990s.

These overall shifts in support mechanisms between 1980 and 1995 occurred for both students supported primarily by federal sources and for those supported by nonfederal sources (this excludes students whose primary source of support is

[50]All the data presented on mechanisms and sources of support for S&E graduate students in this and subsequent sections of this chapter are from the NSF-NIH annual fall survey of Graduate Students and Postdoctorates in Science and Engineering, unless otherwise indicated. In this survey, departments report the primary (largest) source and mechanism of support for each full-time degree-seeking S&E graduate student. No financial support data are collected for part-time students. Many of the full-time students may be seeking master's degrees rather than Ph.D. degrees, particularly in fields such as engineering and the computer sciences. Sources of support include federal agency support (from NIH, other HHS entities, NSF, DOD, or USDA); nonfederal support; and self-support. Support mechanisms include fellowships, traineeships, research assistantships, teaching assistantships, and other. Note that despite this section's emphasis on primary source and primary mechanism of support, most graduate students are supported by more than one source and one mechanism during their time in graduate school, and that individual graduate students often receive support from several different sources and mechanisms in any given academic year. Throughout this section, S&E includes the health fields (medical sciences and other life sciences).

[51]Total federal support of graduate students is underestimated since reporting on federal sources includes only direct federal support to a student and support to research assistants financed through the direct costs of federal research grants. This omits students supported by departments through the indirect costs portion of research grants; such support would appear as institutional (nonfederal) support, since the university has discretion over how to use these funds.

Figure 5-17.
Support for full-time S&E graduate students



NOTE: S&E includes the health fields (medical sciences and other life sciences).

See appendix table 5-34. *Science & Engineering Indicators – 1998*

self-support). Among students whose primary source of support was the Federal Government:

- ♦ the proportion of those whose primary mechanism of support was a research assistantship increased from 55 to 66 percent,
- ♦ the proportion whose primary mechanism was a traineeship decreased from 25 to 15 percent, and
- ♦ those with fellowships as their primary support mechanism fluctuated between 8 and 12 percent of the total over this period.

The Federal Government has an almost negligible role in supporting teaching assistantships.

Among students whose primary source was nonfederal:

- ♦ research assistantships rose from 20 to 29 percent,
- ♦ teaching assistantships fell from 48 to 42 percent,
- ♦ fellowships fluctuated between 13 and 14 percent, and
- ♦ traineeships ranged between 3 and 4 percent of the total.

Patterns of Support by Institution Type

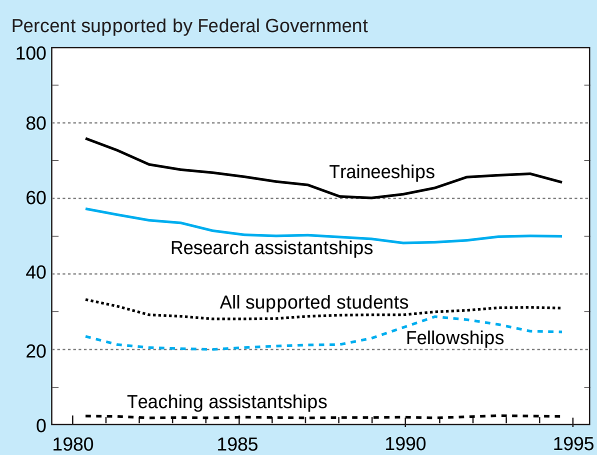
The proportion of full-time S&E graduate students with primary support from various sources and mechanisms differs for private and public universities. (See appendix table 5-35.) A larger proportion of full-time graduate students relies primarily on self-support in private academic institutions as opposed to those in public institutions—39 versus 30 percent in 1995.

Nonfederal sources are the primary source of support for a larger proportion of students in public institutions (50 percent) than in private ones (41 percent). For both private and public institutions, about 20 percent of students receive their primary support from the Federal Government.

A larger proportion of students attending public academic institutions relies on research assistantships and teaching assistantships as their primary support mechanism (30 percent and 23 percent, respectively) than those attending private institutions (21 percent and 13 percent, respectively). This is balanced by greater reliance on fellowships and traineeships in private institutions (14 percent and 8 percent, respectively) than in public ones (7 percent and 4 percent, respectively).

The Federal Government plays a larger role as the primary source of support for some mechanisms than for others. (See figure 5-18.) A majority of traineeships in both private and public institutions (53 percent and 73 percent, respectively) is financed primarily by the Federal Government, as are 60 percent of the research assistantships in private institutions and 47 percent in public institutions. The Federal Government provides the primary support for less than 30 percent of fellowships and less than 2 percent of teaching assistantships in both public and private institutions.

Figure 5-18.
Percentage of full-time S&E graduate students with Federal Government as primary source of support, by primary mechanism of support



NOTES: Data shown here do not include students for whom self-support is their primary source of support. S&E includes the health fields (medical sciences and other life sciences).

See appendix table 5-34. *Science & Engineering Indicators – 1998*

Concern About Forms of Support for S&E Graduate Students

Although there is general agreement that students in S&E disciplines who obtain Ph.D.s from U.S. research-oriented universities are among the best prepared and most successful scientists and engineers in the world, some believe that the challenges of educating scientists, mathematicians, and engineers for the 21st century mandate a new paradigm in graduate training. They contend that doctoral programs could better prepare students for careers outside of academe or basic research by ensuring that they are versatile rather than narrowly specialized and that they are equipped with skills, such as interpersonal communication and the ability to work well in teams, that will enhance their ability to succeed in the real world.

The Committee on Science, Engineering, and Public Policy of the National Academy of Sciences in a report released in 1995, *Reshaping the Graduate Education of Scientists and Engineers,* focuses on Ph.D.s and discusses the changing context of graduate education and the employment trends and prospects for the employment of graduate scientists and engineers. One of the report's major recommendations is: "to foster versatility, government and other agents of financial assistance for graduate students should adjust their support mechanisms to include new education/training grants to institutions and departments." The authors feel that research assistantships, although they offer educational benefits in the form of research skills, focus doctoral programs on the needs of research projects rather than on the broader educational needs of the students.

In June 1995, the Mathematical and Physical Sciences Directorate (MPS) of the National Science Foundation planned and hosted a conference on education and employment patterns of graduates in the mathematical and physical sciences. Conference participants endorsed the following recommendations: (1) mechanisms should be found to encourage a broadening of the training and education experience of MPS graduate students; (2) mechanisms should be examined for shortening the average time to Ph.D. degree in MPS fields; (3) the use of off-campus experience, such as industrial internships, should be increased; and (4) efforts should be made to decrease gradually the proportion of graduate students funded as research assistants and to increase gradually the proportion funded by other mechanisms, including traineeships and fellowships, as well as novel, collective modes of support (NSF 1996d).

The National Science Board Task Force on Graduate Education was established in June 1995 to examine the merits and mix of the several modes of funding support (e.g., research assistantships, fellowships, traineeships) used by NSF to support graduate and postdoctoral education, and the impact of the various modes of support on the experience and preparation of those supported. The members concluded that sufficient data linking both the national data and NSF support data did not exist to make recommendations for major revisions in the mix of NSF funding. Their report (NSB 1996)—delivered in February 1996—did, however, endorse: (1) limited studies on alternative modes of graduate support with defined goals and assessment criteria; and (2) data collection and/or research on funding mechanisms and various aspects of graduate student education and employment.

As part of the call for changes in the manner in which S&E graduate students are supported, the merits of various support mechanisms have been discussed and a number of hypotheses developed about the advantages and disadvantages of different mechanisms. In fact, some of the characteristics of a specific mechanism that are cited as disadvantages by some individuals are cited as advantages by others. For instance, the portability of fellowships and the independence they give to graduate students are seen by some as a distinct advantage because they provide these students with a lot of freedom to pursue a wide variety of interests. Others argue that students with fellowships are more likely than those being supported by traineeships or research assistantships to become isolated from their peers and from the faculty in their departments, and thus may either be less likely to complete their Ph.D. or to take longer to do so. Some argue that although having a fellowship at the beginning of a graduate career may be detrimental, having one when working on a dissertation is highly advantageous.

Similarly, some argue that since research assistantships are directed to the needs of funded research projects, doctoral students can become so involved on a specific project that they have little time for independent exploration or other educational activities, thus limiting the areas in which they acquire experience. A counterargument is that the skills and experience students acquire by focusing on a specific research project are indispensable to the high-quality, state-of-the-art research being conducted at U.S. universities and industrial laboratories. Some argue that strong reliance on research assistantships can bias research and graduate training toward those areas that have long track records rather than to new and exciting areas and that they also may prevent beginning faculty from attracting graduate students. Others argue that it is the widespread availability of research grants that provides young faculty with the opportunity to work closely with graduate students.

Unfortunately, it is extremely difficult to examine many of these hypotheses analytically either because of the absence of data or the inability to capture the hypothesized outcomes quantitatively. In addition, most graduate students depend on multiple sources and mechanisms of support while they are in graduate school, and frequently on different sources and mechanisms of support in different phases of graduate work. This makes it quite difficult, if not impossible in many cases, to identify a one-to-one relationship between a student and a support source or mechanism.

Support Patterns for All S&E Graduate Students Versus Doctoral Recipients[52]

Most S&E graduate students do not go on to receive a Ph.D. It is thus useful to compare the support patterns of those students who *do* earn a Ph.D. with the patterns for all full-time S&E graduate students to see if they differ significantly. Twenty-nine percent of the students receiving Ph.D.s in science and engineering in 1995 reported that their primary mechanism of support during their time in graduate school was a research assistantship. This is close to the percentage (27 percent) of full-time S&E students for whom a research assistantship was reported as the primary mechanism of support. Fellowships and teaching assistantships were reported less frequently as a primary mechanism of support by those students who earned an S&E Ph.D. (2 percent and 6 percent, respectively) than for all full-time S&E graduate students (9 percent and 20 percent, respectively). Traineeships, however, were reported more frequently by those receiving an S&E Ph.D. (13 percent) than for graduate students in general (5 percent). A considerably smaller percentage of students receiving an S&E Ph.D. reported self-support as their primary means of support (18 percent) than did graduate students in general (32 percent). (See appendix tables 5-36 and 5-37.)

Anecdotal evidence suggests that students are more likely to be teaching assistants in the early stages of graduate school when they are doing their coursework than in the later stages when they are working on a doctoral dissertation. Therefore, if students receiving Ph.D.s are more likely to report those mechanisms that supported them in the later years of graduate school as primary, it might explain the small percentage reporting teaching assistantships as a primary support mechanism.

Research Assistantships as a Primary Mechanism of Support

Graduate RAs by S&E Field

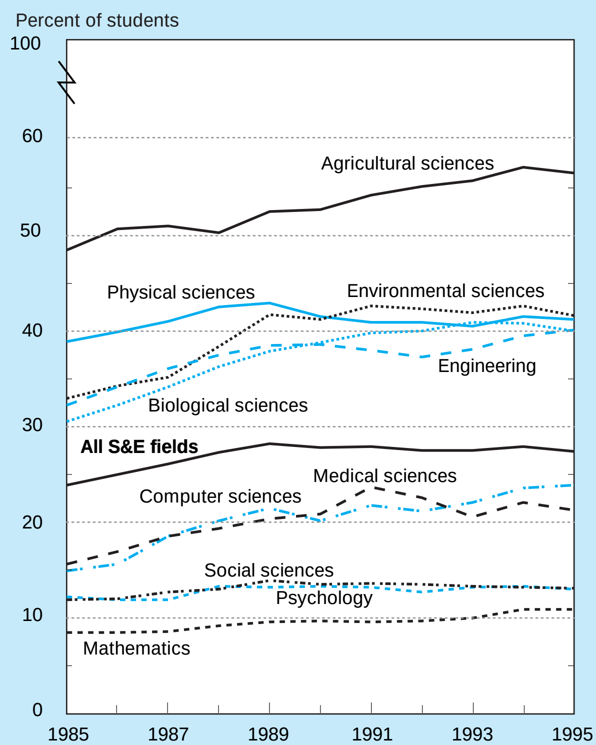
As indicated previously, research assistantships account for 27 percent of all support mechanisms in 1995. However, the mix of support mechanisms—and thus the role of RAs as the primary support mechanism—differs by S&E field. (See appendix table 5-37.) RAs comprise more than 50 percent of the primary support mechanisms for graduate students in astronomy, atmospheric sciences, oceanography, agricultural sciences, chemical engineering, and materials engineering. They account for less than 20 percent in the social sciences, mathematics, and psychology.

The overall number of graduate students with an RA as their primary mechanism of support increased every year between 1985 and 1994 before declining slightly in 1995. (See appendix table 5-38.) Most S&E fields exhibited similar trends, although not all showed a decline in 1995. In just about every S&E field, the percentage of graduate students with an RA as their primary means of support was higher in 1995 than in 1985. The largest increases were in the atmospheric sciences (13 percent), electrical/electronic engineering (12 percent), civil engineering (10 percent), computer sciences, earth sciences, biological sciences, and industrial engineering (all 9 percent). (See figure 5-19.)

All S&E Graduate Students Versus Doctoral Recipients

The relative utilization of an RA as a primary mechanism of support was also fairly consistent at a broad disciplinary level between the Ph.D. and graduate student surveys. (See figure 5-20.) Research assistantships were once again quite prominent in the physical sciences, environmental sciences, and engineering; and were of much less prominence in mathematics, the social sciences, and psychology, confirming the earlier results.

Figure 5-19.
Percentage of full-time S&E graduate students with a research assistantship as primary mechanism of support, by field



See appendix table 5-38.

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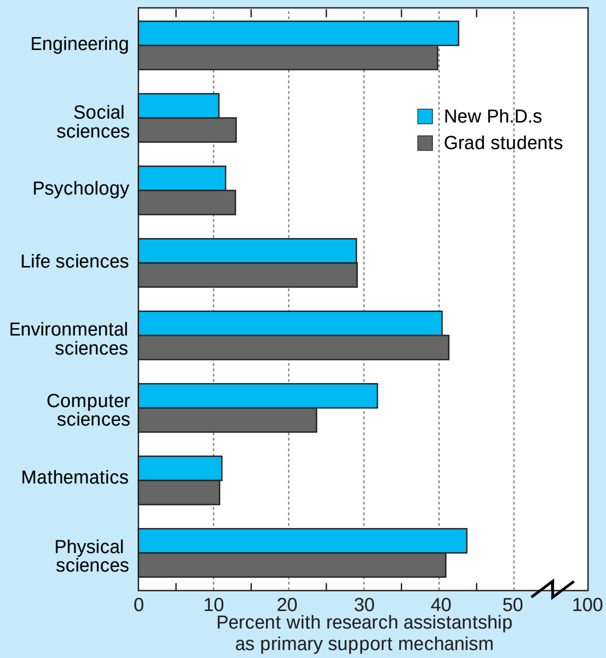
[52]Another source of data on sources and mechanisms of financial support of S&E graduate students is the annual Survey of Earned Doctorates. Students who have just received their Ph.D.s are asked to respond to this survey. One survey question asks them to identify their primary and secondary sources of support during graduate school as well as to check all other sources from which support was received. Validation studies on the quality of the data received from respondents to this survey indicate that the information on mechanisms of support is much better than that on sources. This is especially true for students whose primary support is a research assistantship since they may not always know who is providing the funds that are supporting them. For this reason, the comparison between the graduate student survey and the doctorate survey is confined to mechanisms of support except for self-supported students.

Figure 5-20.
Relative importance of research assistantships as primary mechanism of support for full-time S&E graduate students and new S&E Ph.D.s, by field: 1995



NOTE: Life sciences includes the health fields (medical sciences and other life sciences).

See appendix tables 5-36 and 5-37.

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Sources of Support

In 1995, about one-third of graduate research assistants were in the life sciences, with an additional 30 percent in engineering and 13 percent in the physical sciences. The Federal Government was the primary source of support for about half of all graduate students with an RA as their primary mechanism of support. (See appendix table 5-39.) The Federal Government was the primary source of support for significantly more than half of the research assistants in the physical sciences (75 percent), the environmental sciences (63 percent), and the computer sciences (62 percent); and for considerably less than half in the social sciences (20 percent) and psychology (32 percent). The proportion of graduate research assistants for whom the Federal Government was the primary source of support declined from 58 percent in 1975 to about 50 percent in 1985, where it has remained pretty much through 1995. Similar trends held for the environmental sciences, psychology, social sciences, medical sciences, and engineering. The physical sciences were more variable; chemistry and physics had declining federal shares in both 10-year periods, but astronomy showed little change in the first decade and a considerable decline in the second. The federal share of research assistants in the computer sciences declined from 61 to 49 percent between 1975 and 1986 and then proceeded to increase once again to 62 percent by 1995. (See appendix table 5-40 and figure 5-21.)

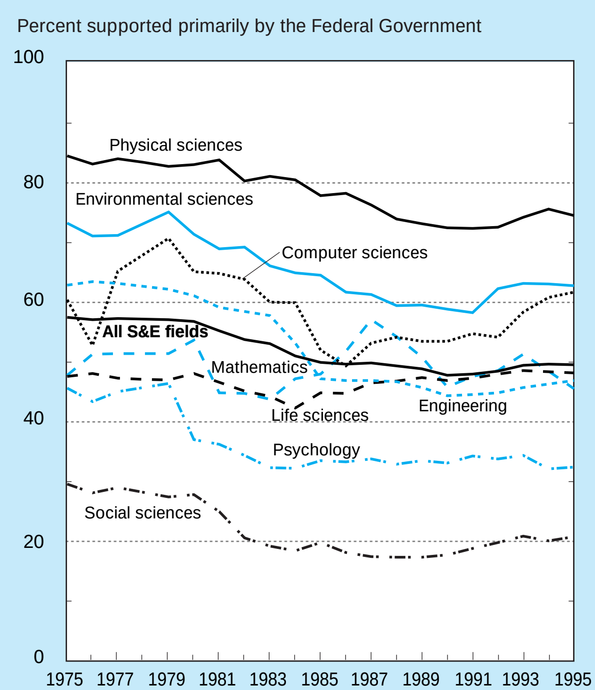
Federal Agency Support[53]

From the early 1970s to the late 1980s, NSF was the federal agency that was the primary source for the largest number of graduate RAs. It was surpassed by HHS (as a whole) in 1989 and by NIH in 1993. Between 1972 and 1995, the percentage of federal graduate RAs financed primarily by NSF declined from one-third to less than one-quarter, while the percentage financed primarily by NIH increased from one-sixth to one-quarter. The DOD share has fluctuated between 10 and 16 percent over the period. (See appendix table 5-41.)

Just as federal agencies emphasize different S&E fields in their funding of academic research, they also emphasize

[53]Only four federal agencies are reported on individually as primary sources of support to S&E graduate students in the Survey of Graduate Students and Postdoctorates in Science and Engineering: DOD, NSF, USDA, and HHS; the latter is reported as two distinct units—NIH and other HHS. NASA has been added to the 1996 survey.

Figure 5-21.
Percentage of research assistants whose primary source of support is the Federal Government, by field



NOTES: Research assistants are students for whom a research assistantship is reported as their primary mechanism of support. Life sciences includes the health fields (medical sciences and other life sciences).

See appendix table 5-40.

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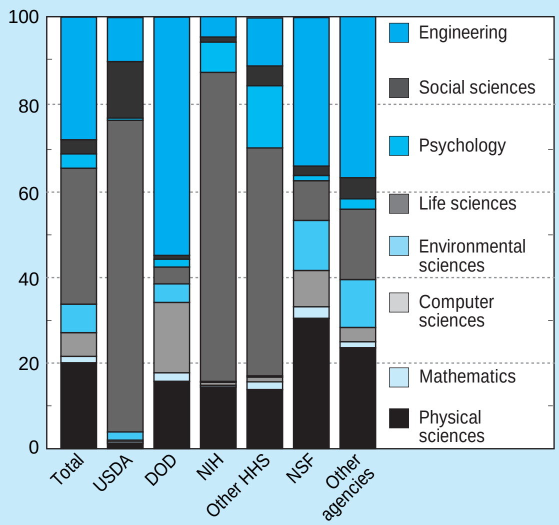
different fields in their support of graduate research assistants. HHS and especially NIH concentrate support in the life sciences (53 and 72 percent, respectively); as does USDA (72 percent). DOD concentrates its support in engineering (55 percent). NSF, on the other hand, has a more diversified support pattern, with one-third in engineering, 30 percent in the physical sciences, and 12 percent in the environmental sciences. (See figure 5-22 and appendix table 5-42.)

Although an agency may place a large share of its support for research assistants in one field, it may not necessarily be an important contributor to that field overall, particularly if it is a small agency in terms of its support for graduate research assistants. (See figure 5-23 and appendix table 5-43.) NSF is the lead supporting agency in mathematics (44 percent of federally supported RAs), the environmental sciences (42 percent), the physical sciences (37 percent), and engineering (29 percent). NIH is the lead support agency in the life sciences (58 percent), psychology (54 percent), and sociology (31 percent). DOD is the lead support agency in the computer sciences (43 percent) and—of those agencies included in the survey—in aeronautical/astronautical engineering (38 percent), electrical/electronic engineering (41 percent), and mechanical engineering (29 percent). USDA is the lead support agency in the agricultural sciences (61 percent) and economics (58 percent).

Figure 5-22.
Field distribution of research assistantships with primary support from a federal agency, by agency: FY 1995

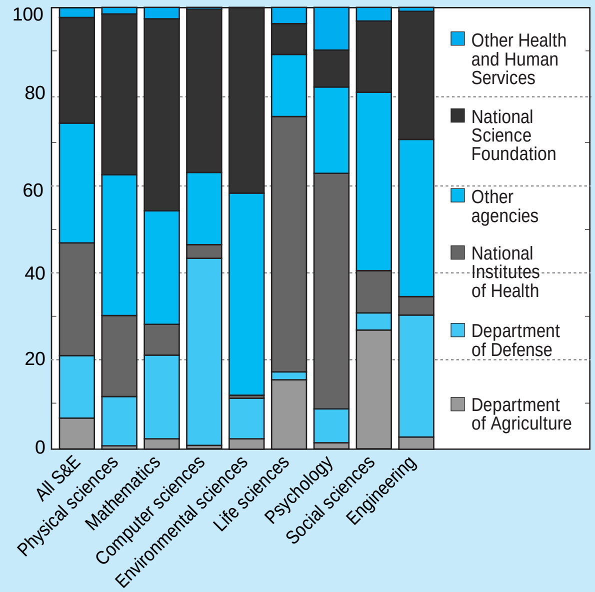


USDA = Department of Agriculture; DOD = Department of Defense; NIH = National Institutes of Health; HHS = Department of Health and Human Services; NSF = National Science Foundation

NOTES: The agencies cited here are the only ones for which graduate support data are reported in 1995. Life sciences includes the health fields (medical sciences and other life sciences).

See appendix table 5-42. *Science & Engineering Indicators – 1998*

Figure 5-23.
Research assistantships supported primarily by the Federal Government, agency shares by S&E field: FY 1995



NOTE: Life sciences includes the health fields (medical sciences and other life sciences).

See appendix table 5-43. *Science & Engineering Indicators – 1998*

The Spreading Institutional Base

Between 1979 and 1995, there was a slight increase in the number of universities and colleges reporting at least one RA as a primary mechanism of support for their S&E graduate students (385 to 415), with the number reaching its highest level (435) in 1993. Not surprisingly, however, there was basically no change in the number of research universities or doctorate-granting institutions reporting the presence of graduate RAs during this period; this number fluctuated between 219 and 224. Since these institutions had probably been receiving research funds over the entire period, it is likely that they were supporting graduate students with research assistantships. Thus, most of the fluctuation and the entire increase in the number of institutions reporting graduate RAs occurred among comprehensive; liberal arts; two-year community, junior, and technical; and professional and other specialized schools. (See text table 5-11.)

The data suggest that most of the increase in the number of institutions reporting RAs as a mechanism of support for their S&E graduate students is due to increasing support from nonfederal sources—probably from the institutions themselves—rather than from the Federal Government.

In addition, throughout this period, considerably fewer institutions reported students with RAs financed primarily by the Federal Government than with assistantships financed primarily from nonfederal sources. This difference is par-

Text table 5-11.
Number of academic institutions reporting graduate research assistantships, by primary source of support and type of institution

Primary source of support and institution type[a]	1979	1980	1981	1982	1983	*1984*	*1985*	*1986*	*1987*	1988	1989	1990	1991	1992	1993	1994	1995
	Number of institutions reporting research assistantships																
All sources of support																	
All institutions	385	400	425	408	413	*332*	*324*	*318*	*320*	412	415	425	413	426	435	421	415
Research and doctorate-granting	220	222	223	224	224	*221*	*217*	*214*	*215*	224	221	222	222	219	222	219	220
Other	165	178	202	184	189	*111*	*107*	*104*	*105*	188	194	203	191	207	213	202	195
Nonfederal sources of support																	
All institutions	352	371	403	383	390	*321*	*310*	*307*	*306*	396	399	404	394	410	418	404	404
Research and doctorate-granting	211	217	218	218	216	*218*	*214*	*213*	*214*	221	221	221	221	218	221	216	219
Other	141	154	185	165	174	*103*	*96*	*94*	*92*	175	178	183	173	192	197	188	185
Federal sources of support																	
All institutions	297	297	316	308	296	*269*	*261*	*254*	*266*	292	299	302	303	305	312	312	303
Research and doctorate-granting	207	207	213	210	209	*210*	*204*	*197*	*200*	209	205	203	205	206	206	209	205
Other	90	90	103	98	87	*59*	*57*	*57*	*66*	83	94	99	98	99	106	103	98

NOTES: Numbers in italics (1984 to 1987) are not comparable with earlier or later years because only a sample of master's-granting institutions rather than the entire population was included in the survey during these years.

[a]These are the institutional categories used by the Carnegie Foundation for the Advancement of Teaching. See chapter 2, "Characteristics of U.S. Higher Education Institutions," for information on these categories. "Other" institutions are all Carnegie-classified institutions except research and doctorate-granting institutions.

SOURCE: National Science Foundation, Science Resources Studies Division, Survey of Graduate Students and Postdoctorates in Science Engineering, various years, unpublished tabulations.

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ticularly pronounced among the "other" Carnegie institutions, 98 of which report RAs supported by the Federal Government in 1995 compared to 185 that report RAs financed by nonfederal sources. Why so many fewer other institutions report the Federal Government as a primary source of funds for research assistantships than receive R&D funds from the Federal Government is unclear.

Outputs of Scientific and Engineering Research

The products of academic research, as noted elsewhere in this chapter, include trained personnel and advances in knowledge. The former have been discussed in chapter 3 of this volume and in the preceding sections of this chapter. This section deals with indicators of advances in knowledge—specifically:

1. The published outputs of natural science and engineering research in a set of refereed journals, discussed in terms of:
   - ♦ **the output volume of research—**by country and field and, in the case of the United States, by sector—using article counts as the indicator;
   - ♦ **patterns of research collaboration—**across national and, for the United States, sectoral boundaries—using multi-author articles as the indicator;
   - ♦ **the use of research outputs in subsequent scientific and engineering research—**again, international and intersectoral—using citation counts as the indicator; and
   - ♦ **the potential practical utility of these research outputs**, as indicated by citations to these articles on U.S. patents.
2. Patents issued to U.S. universities and colleges—i.e., the number and types of patents, institutions with patent awards, and revenue generated by patents and licenses.

Article Outputs

This discussion of article outputs places the United States in the context of other countries contributing to the world scientific literature and examines that literature by field.[54] For a description of the data used in this analysis and its limitations, see “Data Sources for Article Outputs.”

U.S. Articles

In the United States, increased attention has been given to cross-sectoral collaboration in scientific and engineering research. Of particular interest has been the collaboration between industry and universities to enrich the research perspectives of investigators in both settings and to create a means for more efficiently channeling research results toward practical applications. This section discusses the sectoral distribution of U.S. articles, patterns of cross-sectoral collaboration and citation, and multidisciplinary connections of these articles.

Sectoral Distribution. About 142,800 scientific and technical articles were published by U.S. authors in 1995 in the set of 4,800 journals. Of these:

- 71 percent were academic publications;
- 8 percent each were produced by industry and the nonprofit sector (mainly health-related organizations publishing in the biomedical fields—i.e., biology, clinical medicine, and biomedical research); and
- 8 percent were produced by the Federal Government, with an additional 3 percent published by FFRDCs—these latter were mainly in the physical sciences and engineering.

These proportions represent a slightly enhanced position for academic publications since 1981 (68 percent) and an offsetting decline in the federal share including FFRDCs. (See appendix table 5-44.)

The number of *academic papers* increased in all fields but biology (down 25 percent since 1981) and mathematics (down 27 percent). The decrease in biology was partially offset by a strong increase in biomedical research articles, possibly reflecting a shift in focus. No ready explanation is evident for the decline in mathematics outputs. (See appendix table 5-45 for field taxonomy.)

Industry publishing has undergone considerable change over the period, reflecting both growing interest in the biomedical fields and a decline in some more traditional areas of industry activity. Industry publications almost doubled in clinical medicine and tripled in biomedical research; these two fields combined accounted for 4,700 industry articles—or 39 percent of this sector’s total in 1995, versus 19 percent in 1981. Industry publications in physics, chemistry, and engineering and technology—fields traditionally emphasized in industrial research—as well as mathematics all declined in absolute numbers during the 1990s; engineering and technology suffered a particularly steep decline during the 1980s. The precise reasons for these declines are unclear, but they may in part reflect one outcome of the restructuring and refocusing of corporate R&D activities.[55] (See appendix table 5-44.)

Article production by the Federal Government fell and was steady overall for FFRDCs. Federal research output in biomedicine and chemistry was steady. Physics and earth and space sciences articles were up; but a declining output in clinical medicine, biology, mathematics, and engineering and technology outweighed these numerical increases. In the case of *FFRDCs*, increased publications in physics and earth and space sciences balanced declines in other fields. *Nonprofit organizations* increased publication in the biomedical fields, in which they have a combined 11 percent share. (See appendix table 5-44.)

Cross-Sectoral Collaboration. Scientific and engineering research in the United States increasingly involves investigators from several employment sectors, as evidenced by the steady increases in the number and proportion of articles with authors from more than one sector. This increase is evident for all sectors and for all fields—even those with declining output—except mathematics, where the modal pattern remains sole authorship.

Just under one-quarter (24 percent) of all academic papers published in 1995 involved collaboration with one or more authors from other sectors—6 percent from industry, 8 percent each from the Federal Government and not-for-profit sectors, 3 percent from FFRDCs, and 2 percent from other sectors.[56] While this proportion may appear low, it involved roughly 25,900 articles and represented an increase from 20 percent in 1981 (20,100 articles). (See appendix table 5-46.)

The propensity of scientists and engineers employed in other sectors to collaborate across sectoral boundaries was much higher than for their academic colleagues—50 percent in industry, 56 percent in FFRDCs, and 60 percent and above in the other sectors. Moreover, 1981-95 increases in cross-sectoral collaboration have been more pronounced in the nonacademic sectors, ranging from 7 percentage points for nonprofit institutions to 23 percentage points for industry. But most of the cross-sectoral collaborations involved one or more academic authors.

Intersectoral Citation Patterns. Research builds upon previous results, and references to scientific and technical articles reflect their utility in subsequent work. The distribution of such citations to U.S. scientific and technical articles largely—

[54] This section discusses *all* article outputs produced, regardless of originating sector. Not all of these articles originated in the academic sector. However, 71 percent of them did in 1995, and many others involve collaboration with academic researchers or heavily cite the academic literature. Moreover, the non-U.S. literature cannot be cleanly broken out by performing sector.

[55] These declines apparently do not reflect a lack of coverage of newly established journals in the Institute of Scientific Information data set. They were checked against trends in the 1985 and 1991 ISI journal sets, and, while the absolute numbers varied across sets, the direction and relative rates of change for these industry fields were found to be very similar.

[56] These details add up to more than 24 percent because of the incidence of papers involving authors in three or more sectors.

Data Sources for Article Outputs

The article *counts* discussed in this section are based on scientific and engineering articles published in a stable set of about 4,800 journals selected by the Institute of Scientific Information (ISI) as the base for its Science Citation Index in 1981. Fields covered are clinical medicine, biomedical research, biology, physics, chemistry, earth and space sciences, mathematics, and engineering and technology. Appendix table 5-45 lists the constituent fine fields. A database covering the social sciences and behavioral aspects of psychology is being prepared for inclusion in future *Indicators* volumes. The database *excludes* letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

ISI periodically updates its journal coverage, based in part on references to articles in publications not currently included in the database. Given this citations-based updating, ISI's database appears to give reasonably good coverage of a core set of scientific journals (albeit with some English-language bias), but not necessarily of all that may be of regional or local importance. This last point may be particularly salient for the engineering and technology category and for nations with a small or applied science base. In this discussion, *long-term publishing trends* including coauthorship patterns are based on a journal set established by ISI in 1981. *Citation trends* are based on a 1985 journal set. Of course, new journals are always being created, and old ones cease publication. No attempt has been made here to trace the birth and death of journals and their selection for coverage by SCI over the years. All data derive from the Indicators Bibliometrics database prepared for NSF by CHI Research, Inc.

Articles are attributed to sectors and countries by the authors' institutional affiliation, which introduces certain complexities and limitations. For example, a paper is considered to be multi-authored only if two or more authors have different institutional affiliations. The same rule applies to cross-sectoral or international collaborations. For example, a paper written by a U.S. citizen temporarily residing in the United Kingdom in collaboration with someone at his or her U.S. home institution is counted as internationally coauthored, thus possibly overstating the extent of such collaborations. On the other hand, a paper coauthored by a British citizen temporarily located at a U.S. university with another member of the faculty would not be considered internationally coauthored, thus understating the count.

but not entirely—reflects the distribution of the articles themselves, with the bulk of citations going to academic papers. The academic sector contributes 71 percent of all articles and receives 71 percent of all citations. Its citation frequency in clinical medicine, biomedical research, and mathematics is slightly below its publications share; in biology, chemistry, and engineering and technology, the citation frequency exceeds its publications share. (See appendix table 5-47.)

Industry articles are cited at a higher frequency than their share would suggest in the fields of physics and engineering and technology. In recent years, however, both of these fields have experienced a decline in the number of industry articles as well as a decline in the number of citations to these articles.

Linkages Among Disciplines. Research on many scientific challenges increasingly relies on the knowledge and perspectives of a multitude of disciplines and specialties. Biologists seeking to understand cell functions supplement techniques and approaches developed internally with others developed in engineering, chemistry, and physics. Citations in scientific and technical articles that cross disciplinary boundaries are one indicator of the multidisciplinary nature of the conduct of research. The citation patterns among Science Citation Index articles provide a glimpse of connections among major fields and fine fields.[57]

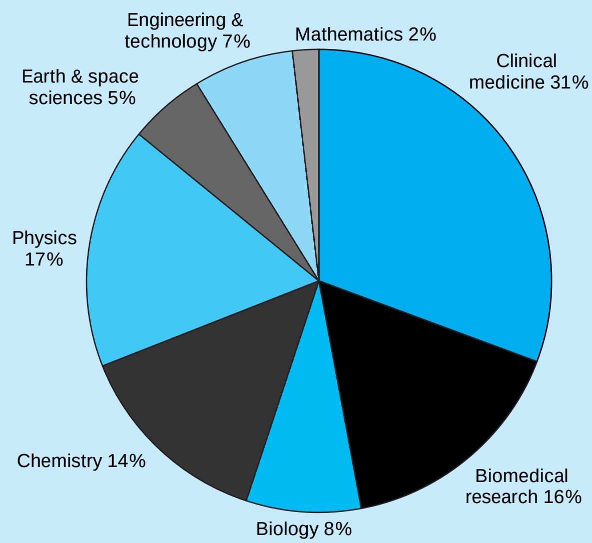
Citations in 1994-95 U.S. articles contained in SCI were aggregated by field.[58] Of the roughly 2.3 million references, articles in the three life sciences—which accounted for 63 percent of the U.S. output—contained 73 percent of the citations, those in other sciences and mathematics 25 percent, and engineering and technology articles just over 2 percent. The distribution of these citations across major fields shows the expected high incidence of references to articles in the same broad field, ranging from 69 to 83 percent in the physical and earth and space sciences to 62 percent in biology. Articles in the combined life science fields cited other life science articles 98 percent of the time. However, the citation patterns are not symmetrical. A greater proportion of citations in the physical sciences, mathematics, and engineering and technology focuses on the life science fields than vice versa. (See appendix table 5-48.)

[57]Data for other indicators of multidisciplinary research activities are not readily available: collaboration of researchers across disciplinary boundaries, multidisciplinary centers, and major multidisciplinary projects—e.g., global climate research—lack readily available representative data or a ready framework for their analysis.

[58]Specifically, references in articles with one or more U.S. authors published in 1994-95 in journals covered by the 1985 SCI set that cited other U.S. articles published in 1990-93.

Examination of fine fields underscores the tight connections among the life science fields. Citations in clinical medicine and biomedical research articles are largely to other articles in these same major fields—90 percent or higher—with most of the remaining citations to biology. This does not mean that their research is isolated from other major fields. About 6,200 citations in clinical medicine and 20,000 in biomedical research articles were to physical sciences, engineering, or mathematics journals. But these represented tiny portions of their total citations—numbering 920,000 and 651,000, respectively. Pharmacy and pharmacology, for example, cite articles in chemistry journals; some biomedical specialties cite chemistry, physics, earth and space sciences, and engineering and technology. The earth and space sciences' connection to biomedical research is intriguing: 4 percent of astronomy/astrophysics citations were to this literature, which in turn received more than 200 citations from general biomedical research articles. These citation links reflect, among other things, the well-publicized adaptation of astronomy imaging techniques to medical diagnosis uses. Otorhinolaryngology articles contain references to the acoustics literature—physics—reflecting a similar connection. (See appendix table 5-48.)

Figure 5-24.
Distribution of articles in world scientific and technical journals, by field: 1995



See appendix table 5-49. *Science & Engineering Indicators – 1998*

Trends in International Article Production

The article counts reported here indicate the volume of scientific publishing in a given field and country, and the field mixes of different countries, as reflected in this set of core journals. In interpreting these counts, note that they reflect field-to-field and country-to-country variations in publishing conventions and differing sizes of scientific infrastructures. The discussion focuses on broad trends and relationships. (See "Data Sources for Article Outputs.")

Worldwide publication of scientific and technical articles in the SCI journal set stood at about 439,000 in 1995. (See appendix table 5-49 for detailed counts.) Almost one-third of these—135,000—were articles in clinical medicine; biomedical research and biology accounted for an additional 107,000 articles. Articles in chemistry, physics, and the earth and space sciences numbered 61,000, 74,000, and 23,000, respectively; there were 31,000 articles published in engineering and technology, and 8,000 in mathematics. (See figure 5-24.)

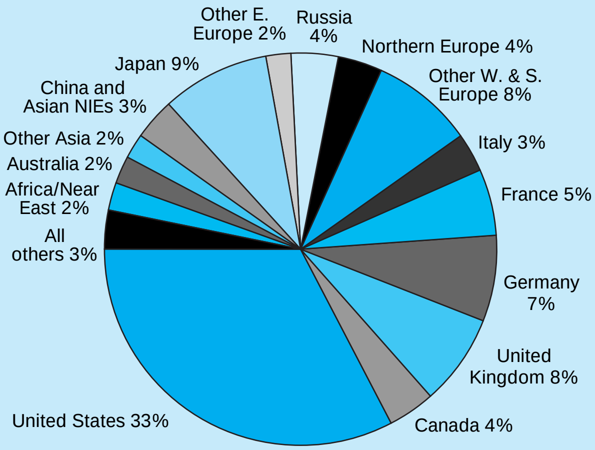
Five nations produced more than 60 percent of all articles in the SCI set of journals in 1995: the United States (33 percent), Japan (9 percent), the United Kingdom (8 percent), Germany (7 percent), and France (5 percent). No other country's output reached 5 percent of the covered articles' total. The regional distribution of these articles is shown in figure 5-25.

From 1981 to 1995, the number of articles published worldwide in the SCI journal set rose by almost 20 percent, compared with 8 percent in the United States alone.[59] This increase coincided with the development or strengthening of national scientific capabilities in several world regions, a development that was particularly pronounced after the end of the Cold War. Thus, a gradual decline in the U.S. world share since the early 1980s continued through the mid-1990s, despite continued growth in U.S. publications output. (See appendix table 5-49.) The European share rose from 32 to 35 percent over the period. It is likely that these gains partially reflect European nations' concerted policies to strengthen the science base in both individual countries and across Europe as a whole.

The article volume of the Central European states—Bulgaria, Czech Republic, Hungary, Poland, Romania, and Slovakia—as a group declined through the early 1990s but rebounded to close to its 1981 level by 1995 (9,100 articles). In contrast, the article output for the nations of the former Soviet Union declined at an accelerating rate after the late 1980s, dropping from about 30,000 in 1981 to 22,000 in 1995; this decrease led to a decline in world share from 8 to 5 percent. This long-term decline in world share is not entirely attributable to the disintegration of the Soviet Bloc, although this certainly continues to contribute to the trend. Articles reflect work done one or more years earlier, and the decline has been gradual and observable over the entire period. It is likely that relative political and scientific isolation, combined with economic difficulties, has affected

[59]These figures are minimum estimates. While figures from an expanded journal set selected in 1985 are higher, they show roughly the same rate of increase. Data from a journal set selected in 1991 suggest a steeper real rate of increase from 1991 to 1995.

Figure 5-25.
Distribution of articles in world scientific and technical journals, by region/country: 1995



NOTE: NIEs are newly industrialized economies.

See appendix table 5-49. *Science & Engineering Indicators – 1998*

the conduct of scientific research in this region.

Southeast Asia's emergence as a potent, high-tech region is well-known,[60] and data on article production present evidence of a robustly developing indigenous S&E base. The Asian nations' world share of publications rose from 11 to nearly 15 percent since 1981, but contradictory trends combined to produce this total. The number of articles produced by Japan increased from 25,100 in 1981 to 39,500 in 1995; this represents a 57 percent increase, three times the world average. Very large percentage increases over the period—though from very low bases—were evident for China (from 1,100 to 6,200 articles) and the newly industrialized Asian economies: Taiwan (from 370 to 3,900), South Korea (170 to 3,000), Singapore (120 to 900), and Hong Kong (from 500 in 1987[61] to 1,100 in 1995). While these gains were realized on a small output base and the combined output remains modest, the combined world share involved rose from one-half of 1 percent to 3.4 percent in a very short time—with no decrease in growth yet evident. On the other hand, India's publications output has contracted by 33 percent since 1981, dropping from 11,700 articles to 7,900 in 1995.[62]

Since the conduct of research reflected in these article outputs requires financial, physical, and human resources—in short, a scientific infrastructure—the potential for further shifts in article distributions can be gleaned from a brief comparison of the economic and article outputs of selected countries. While no simple relationship exists between the relative size of a nation's GDP and its article output volume,[63] there do appear to be some general tendencies. (See appendix table 5-50.) For the nations shown, the number of papers produced per billion U.S. dollars of GDP ranges from 2 to 54. (See figure 5-26.) Israel and a number of smaller European nations rank highest, exceeding 30 articles per billion U.S. dollars of GDP. The United States is in the middle range, with 20 articles per billion dollars of GDP. Nations with fast-developing economies have smaller than expected article outputs. There is also a large number of nations with economies that are small, or small on a per capita basis, that contribute little to the world's scientific output.

Field Distribution of Articles

As noted earlier, for all countries combined, the life sciences accounted for the bulk (55 percent in 1995) of the articles in the SCI database. (See figure 5-24.) The nearly 20 percent increase in world articles from 1981 to 1995 was driven by increases in physics (63 percent), the earth and space sciences (36 percent), and biomedical research (30 percent). Biology and mathematics publications declined in number (by 11 and 23 percent, respectively), possibly signaling the demise of some journals in these fields. Chemistry and clinical medicine articles increased slightly (by 12 and 16 percent, respectively); while those on engineering and technology did not increase at all. Because of the large number of articles produced each year, shifts in field distribution have been small but noticeable. (See text table 5-12.) For example, the life science share fell by 2 percentage points; those of mathematics and engineering and technology fell by 1 point. Within the life sciences, biology's share fell by 3 points while biomedical research articles increased, suggesting a gradual shift in research focus. The share of physics articles increased by 5 percentage points over the period.

U.S. Article Output in the International Context

The roughly 142,800 U.S. articles published in 1995 accounted for about 33 percent of the world's total, up in number from 132,300 in 1981 but down from the almost 36 percent share of world total these articles then represented. This drop reflects the fact that other nations' publications output has expanded relatively faster than that of the United States. U.S. output has grown in some fields: notably—in round numbers—from about 22,000 to 28,000 in biomedical research, and from 13,000 to 18,000 in physics. It has

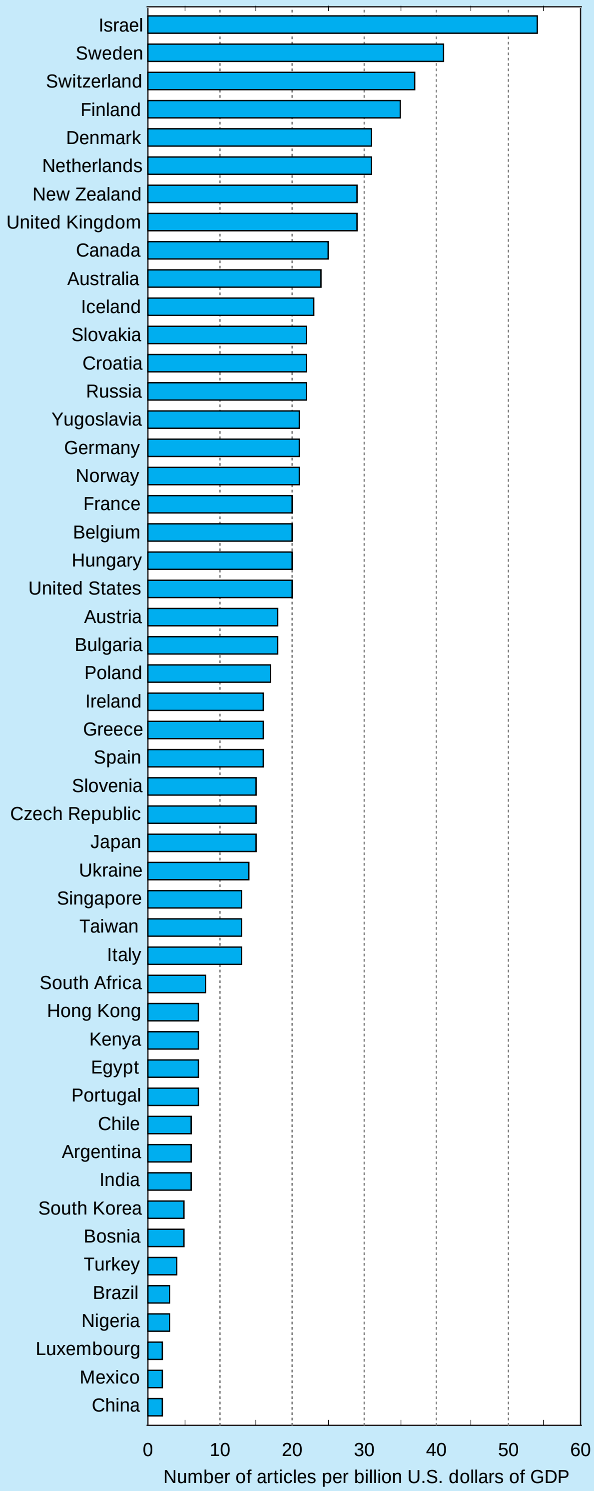
[60]The emergence of these Asian countries in high-tech economic activity is described in NSF (1995a). The expansion of their education activities in science, engineering, and technology is described in NSF (1993a). See also discussions in chapter 2 on higher education developments and chapter 4 on patterns of R&D support.

[61]Hong Kong's data for years before 1987 were reported with the United Kingdom's.

[62]See Raghuram and Madhavi (1996). The authors note that this decline cannot be attributed to journal coverage in SCI, and that it is paralleled by a decline in citations to Indian articles. They speculate that an aging scientific workforce may be implicated, along with a "brain drain" of young Indian scientists whose articles would be counted in the countries in which they are published, not in the author's country of origin.

[63]The simple correlation between GDP share and share of world articles produces an r^2 of 0.75. However, once the United States is removed, the r^2 drops precipitously to 0.29.

Figure 5-26.
Scientific and technical article output of selected countries, per billion U.S. dollars of GDP: 1995



See appendix table 5-50. *Science & Engineering Indicators – 1998*

Text table 5-12.
Share of world scientific and technical articles, by field
(Percentages)

Field	Share of publications 1981	Share of publications 1995	Change, 1981-95
Total life sciences	57.2	55.1	–2.1
Clinical medicine	31.5	30.7	–0.9
Biomedical research	15.0	16.4	1.4
Biology	10.6	8.0	–2.7
Total physical sciences	31.7	36.2	4.4
Chemistry	14.8	14.0	–0.8
Physics	12.3	16.9	4.6
Earth and space sciences	4.6	5.3	0.7
Engineering and technology	8.3	7.0	–1.4
Mathematics	2.8	1.8	–1.0

See appendix table 5-51. *Science & Engineering Indicators – 1998*

been roughly steady in clinical medicine, at about 50,000. Declines in output occurred in biology (from 15,000 to 11,000), engineering and technology (from 12,000 to 10,000), and mathematics (from 4,000 to 3,000). (See appendix table 5-49.)

But the U.S. article portfolio is quite different from that of other major producers (see “The Science and Technology Portfolios of Nations,” below); consequently, U.S. world share, and changes in world share, are field dependent. The biggest relative declines occurred in engineering and technology (7 percentage points) and biology (6 points). Smaller declines in the U.S. share (2 to 4 percentage points) occurred in clinical medicine, the earth and space sciences, and mathematics. The physics share contracted by nearly 5 points, while chemistry held steady.

The Science and Technology Portfolios of Nations

Nations make implicit or explicit choices about the nature of their science and technology portfolios through their allocation of resources; the results of these choices are reflected, to some degree, in their article output data. (See appendix table 5-51.) It is clear that different nations have very different choice patterns, and that these patterns can—and do—change over time.[64]

Figure 5-27 shows the 1995 portfolio mix of a range of countries, arrayed by the fraction of their total output devoted to clinical medicine and biomedical research (which account for about half of these articles worldwide). The differences in emphasis are striking. The United States, United Kingdom, countries of Northern Europe, several smaller Western European nations, and Chile all emphasize these fields quite heavily. At the other end of the spectrum are China and the rapidly growing newly industrialized Asian econo-

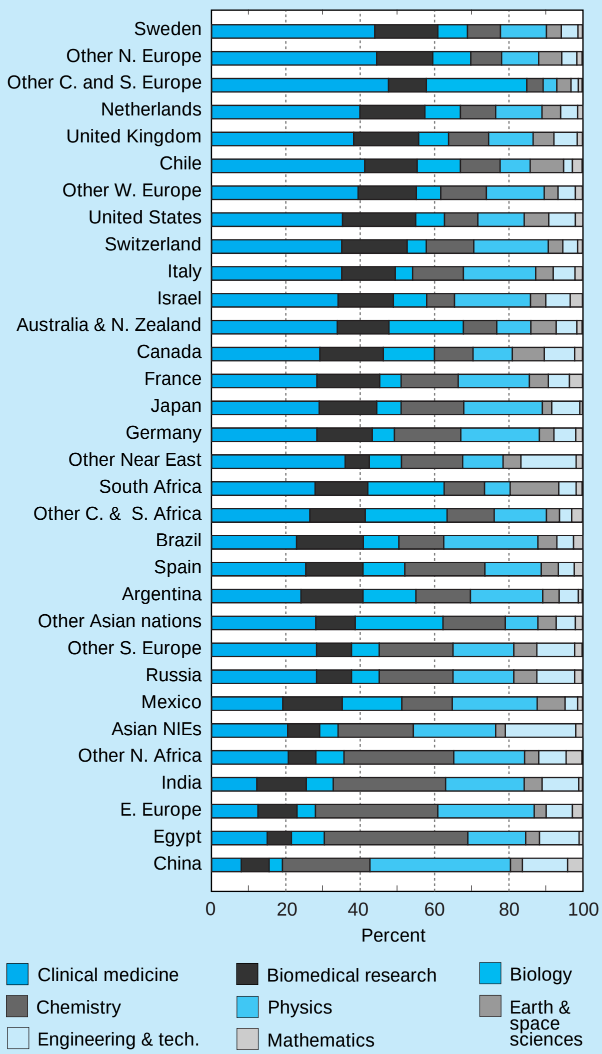
[64] See also the discussion in chapter 2, “Worldwide Increase in S&E Educational Capabilities,” on the field distributions of S&E degrees of various nations.

mies, India, Eastern Europe, Egypt, and Mexico, each of which has a small fraction of its portfolio in these fields.

In contrast, France, Germany, Spain, Italy, Eastern European nations, Russia, Mexico, Japan, the newly industrialized Asian economies (especially), India, China, and Egypt put far more weight than the world average on chemistry and physics. Russia, China, Egypt, and—again especially—the Asian economies are noteworthy for their concurrent emphasis on engineering and technology.

Countries tend to shift the focus of their scientific activities gradually over time. (See appendix table 5-51.) Major shifts toward chemistry—and, to a lesser extent, physics—are evident for some of the world's developing nations and regions. Russia, which once had an extremely heavy stake in these traditional fields, is shifting away from them. Biology research is in relative decline around much of the world, in favor of increases in the more applied life science disciplines. Engineering and technology has lost ground in many national portfolios relative to other fields. Note, however, that the portfolios of some of these countries were very small in 1981, making relatively large percentage changes possible as publication counts have grown.

Figure 5-27.
Distribution of selected countries' and regions' scientific and technical articles, by field: 1995



NOTE: NIEs are newly industrialized economies.

See appendix table 5-51. *Science & Engineering Indicators – 1998*

International Scientific Collaboration

In many fields, cutting-edge science is increasingly dependent on knowledge, perspectives, and techniques that cross traditional disciplinary boundaries. Often, the scope of the problem (e.g., constructing a coordinated array of widely spaced telescopes or mapping global environmental trends), combined with complexity and cost, suggests or even dictates broad collaboration that increasingly involves international partners. Both trends—increased collaboration and growing international cooperation—can clearly be seen in the publications data. A pervasive trend toward greater scientific collaboration affects all article fields, and a steadily growing fraction of most nations' papers involves international coauthorship. This section examines these trends, the U.S. position in international collaboration, who collaborates with whom, how developing and developed nations compare, and what collaboration patterns exist for and among Asian nations.[65]

Trends in Scientific Cooperation. A pronounced worldwide tendency exists toward greater scientific collaboration, as evidenced by patterns of corporate coauthorship of scientific and technical articles written by authors located in two or more different institutions.[66] This phenomenon can be observed in every field, every sector, and most countries. Moreover, such collaboration is increasingly international, involving researchers from different nations.[67] In 1995, the proportion of the world's papers that were coauthored (in this multi-institution sense) was 50 percent; almost 30 percent of these involved international collaboration. (See appendix table 5-52.) The number of coauthored articles increased from 121,000 in 1981 (33 percent of the total) to 219,400 in 1995

[65]The data discussed in this section involve the incidence of article coauthorship in which the authors' institutional affiliations are located in two or more countries. These data have certain limitations. For example, a paper written by a U.S. citizen temporarily residing in the United Kingdom in collaboration with someone at his or her U.S. home institution is counted as internationally coauthored, thus possibly overstating the extent of such collaborations. On the other hand, a paper coauthored by a British citizen temporarily located at a U.S. university with another member of the faculty would not be considered internationally coauthored, thus understating the count. Further, the data suggest a growing trend toward multiple-country coauthorship. However, the trends discussed here are sufficiently broad-based and robust to give confidence in the measure.

[66]This provides a lower bound estimate and understates the true number of papers with multiple authors. The database counts corporate coauthorships—that is, two or more authors are counted as coauthors only if they are at two or more institutions. The trends reported here are internally consistent.

[67]Among the causes of these increases are no doubt the extent of advanced training students and recent doctorate-holders receive outside their native countries and the web of intergovernmental agreements inviting or requiring multinational participation in some research activities.

(50 percent). Over this period, the number of internationally coauthored articles worldwide increased by 200 percent—from 21,000 to 63,800—while the total number of articles rose by about one-fifth. This increase in turn caused a rise in the proportion of all papers published worldwide involving some degree of international coauthorship—from 6 percent in 1981 to 15 percent in 1995.

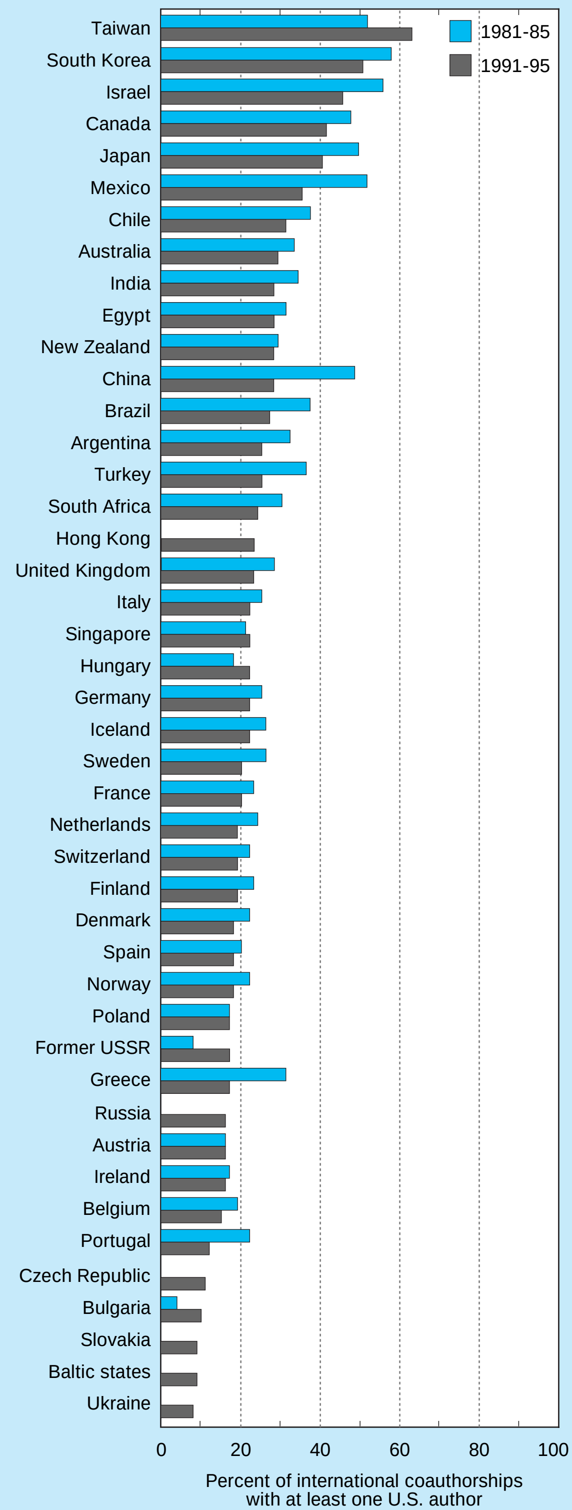
Corporate coauthorship varies by field. For example, in the 1991-95 period, the U.S. average of coauthored articles was 56 percent, but clinical medicine was well above that with 64 percent of its articles coauthored. Chemistry, engineering and technology, biology, and mathematics had lower rates of corporate collaboration, at 39, 43, 46, and 47 percent, respectively; the other fields were close to the mean. (See appendix table 5-53.) Wider variation exists in rates of international collaboration. Measured against all coauthored articles, the U.S. average was 29 percent for 1991-95, but this was heavily influenced by a 19 percent rate of clinical medicine articles. On the other hand, 51 percent of coauthored mathematics articles involved international collaboration, as did 46 percent of physics and 42 percent of earth and space sciences articles.

The position of the United States in international collaboration (as evidenced by coauthorship) is characterized by two complementary trends. For almost every nation with strong international coauthorship ties, the number of articles involving a U.S. author rose strongly between 1981 and 1995. During this period, however, many nations broadened the reach of their international collaborations, causing a gradual diminution of the U.S. share of the world's internationally coauthored articles. (See appendix table 5-54.)

The United States has one of the highest coauthorship rates in the world: 58 percent of U.S. articles published in the ISI journal set involved corporate coauthorship in 1995, up from 43 percent in 1981. U.S. authors contributed 42 percent of all coauthored articles and participated in 45 percent of all internationally coauthored articles—well in excess of the 33 percent U.S. article share. But of all U.S. articles published in 1995, only 18 percent involved international coauthors, a smaller percentage than that of most other nations. These numbers reflect the sheer size of the domestic U.S. science base. Worldwide, domestic and international coauthorships have also risen, often more steeply (in terms of the proportion of a country's papers involved) and to higher levels than in the United States. For most countries, the share of internationally coauthored articles ranges from 25 to 40 percent of their output; but Japan and India (15 percent each), Russia (21 percent), and other former Soviet countries (13 percent) are well below this range. (See appendix table 5-52.)

Who Collaborates With Whom? International scientific collaboration, as measured by the percentage of a country's multi-author articles involving international coauthorship, centers to a considerable degree on the United States. (See figure 5-28.) In the first half of the 1990s, about one in five internationally coauthored papers published in major European industrial nations involved collaboration with the United

Figure 5-28.
Percentage of internationally coauthored articles involving one or more U.S. authors, for selected countries



See appendix table 5-54. *Science & Engineering Indicators – 1998*

States; for many other nations, the rate was much higher. For example, Japan and India, with low rates of international collaboration, shared 40 and 28 percent of their international coauthorships with the United States, respectively; China, 28 percent; Taiwan, 62 percent; and South Korea, 50 percent. (See appendix table 5-54.) Rates of collaboration with the United States ranged from 25 to 35 percent for major South and Central American countries, 45 percent for Israel, and near 30 percent for Australia and New Zealand. Countries of the former Soviet Union collaborated relatively less frequently with U.S. partners, as did all Central European nations except Hungary.

Examination of this same indicator for an earlier period—1981-85—suggests that the scientific world is witnessing the development of new centers of activity, probably reflecting continuing political and economic developments in the wake of the end of the Cold War. Comparison of 1981-85 and 1991-95 data shows strong growth in the number of articles with authors from more than one nation, and—at the same time—a broadening of international collaborative ties. (See appendix table 5-54.) While coauthorship with the United States continued to rise in terms of number of publications, it declined with many countries in terms of the share of all their internationally coauthored articles. (See figure 5-28.) The share drop (but not a decline in the number of articles) in collaboration with the United States was most striking for China—roughly 20 percentage points—but is evident for most other countries as well. A similar pattern, though much attenuated, is evident for the major European industrial nations.

In the Asian region, the trends are somewhat erratic, but generally indicate the development of regional cooperative patterns involving—especially—China and the newly industrialized economies. Regional collaboration, as measured by the proportion of coauthored articles with an author from another Asian country, is almost 25 percent for South Korea, in excess of 30 percent for Singapore and Hong Kong, and around 15 to 20 percent for most other countries; India and Japan have lower rates of coauthorship. The degree of collaboration with Japan has increased for some but not all of these nations, and the absolute number of papers with Japanese coauthors has risen. Collaboration with the United States is high for these economies: Taiwan, 62 percent; South Korea, 50 percent; Japan, 40 percent; China and India, 28 percent each; and the other Asian nations about one-fifth. Collaboration with Europe is less prominent, ranging from 10 to 25 percent for the entire continent.

The Central European states have fairly strong regional collaborative ties, given the relatively small volume of their collective publications output. They share 10 to 15 percent of their internationally coauthored articles. From roughly half to 60 percent of these articles are shared with the rest of Europe—most strongly with Germany (around 20 percent); and the United Kingdom, France, and Italy combined (15 to 20 percent). These figures have increased over their levels in the 1980s, as ties to the countries of the former USSR have generally attenuated in the 1990s. International collaboration involves U.S. scientists in about 10 percent of the cases in Czech Republic, Slovakia, and Bulgaria; in excess of 15 percent for Poland; and over 20 percent for Hungary.

Russia's collaborative ties are mainly with the United States (roughly 15 percent); Germany (15 percent); and the United Kingdom, France, and Italy combined (20 percent). The rest of Europe represents 20 percent; collaboration with other former member states represents 10 percent. As a group, the countries of the former Soviet Union (except the Baltic states) have much the same pattern, though with weaker cooperative links to the United States and Germany, and stronger links to other European nations. Scientists in the Baltic states who collaborate internationally tend to do so with colleagues in the Scandinavian countries (25 percent), attesting to strong cultural and regional ties among these nations.

The U.S. pattern of international coauthorship stands in sharp contrast to those just described (as it must, given the high percentages of U.S. involvement in most other nations' international collaborations). No one country contributes more than 10 percent to the U.S. articles with multinational authors. Canada, the United Kingdom, Germany, all of Southern Europe, the Northern European countries, and all other Western European nations combined contribute between 7 and 10 percent each; the Eastern European and former Soviet states combined contribute another 7 percent; Japan and the other combined Asian nations contribute about 8 percent each. This is a much more even distribution of international collaborative ties than is seen for the other countries.

Countries with small indigenous science establishments tend to have higher levels of international coauthorship as a percentage of their total article output than do those with larger, more mature systems. Rather than collaborating regionally, scientists from developing nations tend to work with those from major science-producing nations. In the case of small but mature nations (e.g., the Northern or smaller Western European countries), this pattern is augmented by regional collaboration. Political isolation, economic disruption (as in the case of the states of the former Soviet Union), and cultural or language barriers (as in the case of Japan) can influence these patterns and result in unusually low degrees of international collaboration.

Use of Scientific and Technical Articles in Subsequent Research

The global dimensions of the conduct of scientific activity, discussed above in terms of international research collaboration, are also reflected in the patterns of citations to the literature. Scientists and engineers around the world cite prior work done elsewhere to a considerable extent, thus demonstrating the usefulness of this output in their own work. Citations to one's own country's work are generally prominent and show less of a time lag than citations to foreign outputs. Regional citation patterns are evident as well, but citations to research outputs from around the world are extensive.

U.S. scientific and technical articles are cited by virtually all mature scientific nations in excess of the U.S. output's world share. (See appendix table 5-55.) This broad finding needs to be qualified, however, since citation patterns and practices vary by field. More specifically, the finding holds for chemistry, physics, biomedical research, and clinical medicine. U.S. articles in the remaining fields tend to be cited at or slightly below their world output share.

Not surprisingly, all countries cite their domestic literature well in excess of their respective world shares, but no other country cites its domestic literature as heavily as does the United States—67 percent. Another 14 percent of U.S. citations are to British, French, German, and Italian articles; 7 percent each to the articles of other European nations and Asia and the Pacific (4 percent for Japan);[68] and 3 percent to Canadian articles.[69] The high U.S. self-citation rate might conceivably reflect insularity, but the high proportion of involvement of U.S. scientists in internationally coauthored articles casts doubt on this interpretation.

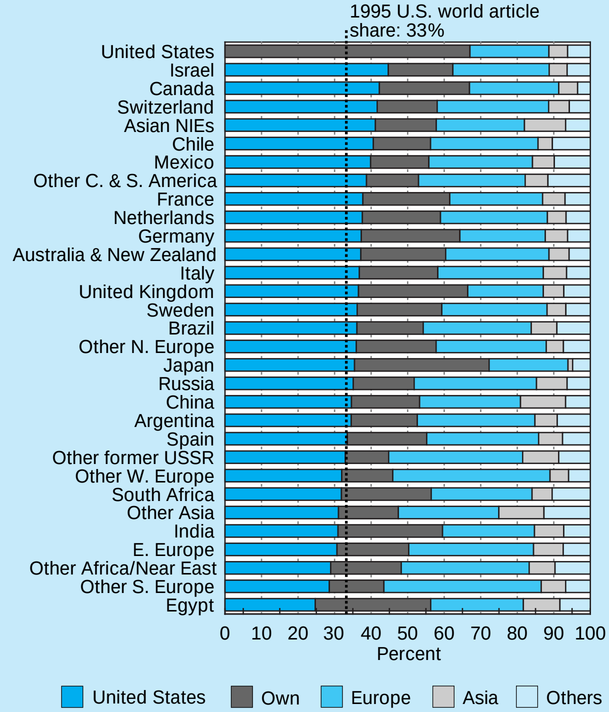
A comparison of citations to the U.S. literature (the leftmost column of appendix table 5-55) with those to a nation's domestic output (diagonal values) shows a generally larger share of total citations to U.S. than to domestic articles. (See figure 5-29.) In part, of course, this reflects the scale and breadth of the U.S. scientific and technical establishment. Yet there is no compelling reason why one country's literature should be cited in proportion to its world output share by any other country. For example, no European country cites another European country's output at the rate of the cited country's article share, despite the many arrangements that foster collaboration and knowledge flows among the European nations. It appears reasonable to conclude that scientists elsewhere find the outputs from U.S. research quite useful in the conduct of their own work, as evidenced by the volume of references to the U.S. literature in other countries' scientific and technical articles.

The citations in articles from the four largest European industrial nations—the United Kingdom, France, Germany, and Italy—refer to their respective domestic outputs 21 to 30 percent of the time, to articles of the other countries in the set 11 to 18 percent of the time, and to U.S. articles between 36 and 38 percent of the time. Output from the rest of Europe receives 10 to 12 percent of citations; Canada, 3 percent; and Asia and the Pacific, 7 percent (4 to 5 percent to Japanese articles).

The citations from other Western, Southern, and Northern European nations refer to their own domestic literature 10 to 23 percent of the time—reflecting their generally smaller domestic science base—and the four large European industrial nations 18 to 28 percent. The United States receives 32 to 42 percent of the citations; and other European nations combined, 10 to 17 percent. Asia and the Pacific receive 7 to 9 percent of these nations' citations.

The pattern of citations among Central European nations is similar, with a regional component of 3 percent, and an additional 1 to 3 percent referring to the literature of the former Soviet states. A stronger orientation than for most other countries is evident toward Asia and the Pacific, which receive a combined 9 to 11 percent of the citations.

Figure 5-29.
Citations in selected countries' scientific and technical literature to U.S., own, and major regions' articles: 1995



NOTES: "Own" means countries' citations to their own literature; for regional groupings, to the literature of that group of countries. NIEs are newly industrialized economies.

See appendix table 5-55. *Science & Engineering Indicators – 1998*

Somewhat less reliance on European science output, somewhat greater reliance on that of the United States, and more of a regional Asian/Pacific focus mark the citation ties of the Asian nations. China and the newly industrialized economies cite their own articles only 10 to 20 percent of the time, but cite each others' articles 12 to 16 percent of the time—high relative to the size of their science bases. Japan's pattern is different (37 percent self-citation and only 2 percent of citations to articles from other states in the region); as is India's (29 percent self-citation, 6 percent citation to Japan's output, and 2 percent to the rest of the region).

Patent Outputs

Governments assign property rights to inventors in the form of patents to foster inventive activity that may have important economic benefits. The U.S. Patent and Trademark Office grants such government-sanctioned property rights in the form of patents for inventions deemed to be new, useful, and nonobvious. This section discusses recent evidence about strength-

[68]Asia and the Pacific includes Australia and New Zealand.

[69]Percentages do not total 100 because of rounding.

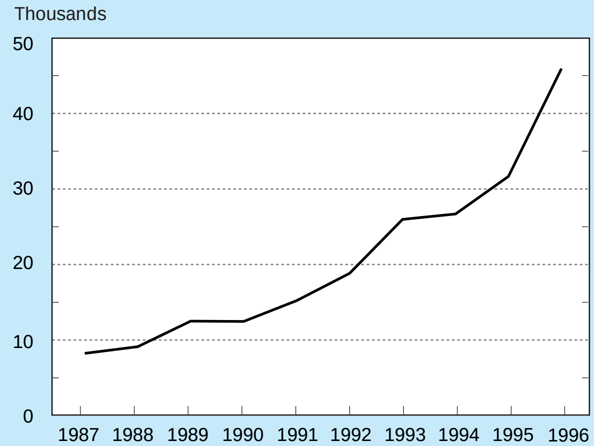
ening ties between scientific and technical research and patenting activity, trends in academic patenting, and income from these activities flowing to universities and colleges.[70]

Citations in U.S. Patents to the Scientific and Technical Literature

Patent applications cite "prior art," including scientific and technical articles, that contributes materially to the product or process to be patented and upon which it improves. These citations provide some indication of the potential contributions of published research results to patentable U.S. inventions. A number of caveats apply. The use of patenting varies by industry segment, and many citations on patent applications are to prior patents. Industrial patenting is only one way of seeking to ensure firms' ability to appropriate returns to innovation and thus reflects, in part, strategic and tactical decisions. Such patenting can be defensive or forward-looking, or can lay the groundwork for cross-licensing arrangements. Most patents do not cover specific marketable products but might conceivably contribute in some fashion to one or more such products in the future. These caveats notwithstanding, citations to the scientific and technical literature give one indication of the linkage between research outputs and innovative applications, as judged by the patent applicant.

The scientific and technical literature is increasingly likely to be cited on U.S. patents. The percentage of U.S. patents citing at least one scientific or technical article increased from 11 percent in 1985 to 14 percent in 1990 and 23 percent in 1995.[71] To further explore this trend, citations to U.S. research articles included in the SCI set of journals were identified and classified by field and performer sector for all U.S. patents issued from 1987 through 1996. The number of such citations increased from 8,600 in 1987 to 47,000 in 1996[72] (see figure 5-30 and text table 5-13), and their field distribution shifted dramatically toward the life sciences. The rise in the number of citations held for all fields and for papers from all sectors. (See appendix table 5-56.) The fastest growth, however, occurred in the life sciences. The biomedical research share rose from 28 to 44 percent, and that of clinical medicine rose from 26 to 29 percent. The combined share of physics, chemistry, and engineering and technology citations dropped from 43 to 24 percent of these patent citations—but not their absolute number, which rose from 4,018 in 1988 to 11,246 in 1995.

Figure 5-30.
Number of citations on U.S. patents to U.S. scientific and technical articles



NOTE: The recent increase may partly reflect changed processing of patent applications by the U.S. Patent and Trademark Office, the ease of locating scientific and technical articles, and greater incentive to cite them.

See appendix table 5-56. *Science & Engineering Indicators – 1998*

Citations to academic articles rose faster than to those from industry or government authors, pushing the academic share of the total from 49 to 55 percent. The increase was driven by strong gains in chemistry (where the academic share rose from 58 percent in 1988 to 65 percent in 1995), physics (from 29 to 40 percent), and engineering and technology (from 31 to 44 percent).

A recent study examined all citations on the front page of all 397,660 U.S. patents awarded in 1987-88 and 1993-94 (Narin, Hamilton, and Olivastro 1997). Many of these citations are to other patents, but among all citations, 430,226 referred to nonpatent materials; of these, 242,000 were judged to be science references, of which 175,000 were to materials in SCI journals. Among the study's findings are a rapid increase in the number of citations to scientific and technical articles on U.S. patent applications; a shortening of the time elapsed between publication and citation on patents; and a large proportion of such citations to publicly funded science (defined by the authors to include articles by academic, nonprofit, and government authors).[73] References tended to be to articles appearing in nationally and internationally recognized, peer-reviewed journals, including journals publishing basic research results, and to be field- and technology-specific.[74] The authors note both national (U.S. patents citing U.S. authors with greater than expected frequency) and regional components in the patterns of citations.

[70]Chapter 6 presents a more comprehensive discussion of patented inventions in all U.S. sectors.

[71]Personal communication with Francis Narin and Kim Stevens, CHI Research, Inc.

[72]The U.S. Patent and Trademark Office changed its processing of patent applications during this period, and some of the observed increase probably reflects these changed practices and applicants' responses to them. Furthermore, greater ease of locating—electronically—the relevant prior art, and greater incentives to include all possible elements thereof, may also contribute to the increase. Nevertheless, the direction of the trends reported here is congruent with those in academic patenting, discussed below. The number of citations reported here refers to articles published in an 11-year span, as follows: 1987 patent citations are to articles published in 1973 to 1984, 1995 citations to those published in 1981 to 1992.

[73]This latter finding is broadly consistent with results obtained by Mansfield (1991), focusing on academic science only and using a very different study framework and approach.

[74]See tables 2 and 3 in Narin, Hamilton, and Olivastro (1997).

Text table 5-13.
Number and distribution of citations on U.S. patents to the U.S. scientific and technical literature, by field

Patent issue year	Total	Clinical medicine	Biomedical research	Biology	Chemistry	Physics	Earth & space sciences	Engineering & technology	Mathematics
				Number of citations					
1987	8,597	2,221	2,391	168	1,181	1,286	104	1,244	0
1988	9,495	2,423	2,749	220	1,212	1,595	81	1,211	2
1989	12,950	3,193	3,978	304	1,536	2,356	117	1,461	2
1990	12,906	3,417	3,818	306	1,673	2,169	76	1,443	3
1991	15,718	4,208	5,199	437	1,921	2,424	123	1,401	2
1992	19,404	5,294	6,949	436	2,451	2,667	92	1,494	18
1993	26,694	7,393	10,736	547	3,027	3,024	93	1,850	21
1994	27,422	7,223	10,334	675	3,114	3,589	121	2,349	14
1995	32,500	9,171	12,713	812	3,689	3,366	134	2,593	19
1996	47,059	13,630	20,617	1,344	4,533	3,498	193	3,215	25
				Percentage of citations					
1987	100	26	28	2	14	15	1	14	0
1988	100	26	29	2	13	17	1	13	0
1989	100	25	31	2	12	18	1	11	0
1990	100	26	30	2	13	17	1	11	0
1991	100	27	33	3	12	15	1	9	0
1992	100	27	36	2	13	14	0	8	0
1993	100	28	40	2	11	11	0	7	0
1994	100	26	38	2	11	13	0	9	0
1995	100	28	39	2	11	10	0	8	0
1996	100	29	44	3	10	7	0	7	0

NOTE: Count for 1987 patents is of citations to articles published in 1973-84; for 1988 patents to articles published in 1974-85, etc.

See appendix table 5-56.

Science & Engineering Indicators – 1998

Patents Awarded to U.S. Universities

Patents may be awarded on the results of academic R&D deemed to have potential utility for the development of new or improved products or processes. While the bulk of academic R&D is basic research (i.e., research that is not undertaken to yield or contribute to immediate practical applications), data on the patenting activities of universities and colleges suggest that academic institutions are giving increased attention to the potential economic benefits that may be inherent in their R&D results. A growing number of universities and colleges are applying for, and receiving, protection for results of work conducted under their auspices, even though the returns on such patents remain low, on average, when measured against their R&D expenditures. (See "Income From Patenting and Licensing Arrangements," below.) The number of patents and institutions involved is small when viewed against the backdrop of all U.S. patenting activity, but the increases are of interest.

After slow growth in the 1970s, the number of academic institutions receiving patents increased rapidly in the 1980s from about 73 early in the decade to more than double that by 1989 and 168 by the mid-1990s.[75] This development, pronounced during the 1980s and more muted in this decade, affected the number of both public and private institutions receiving patent awards. (See figure 5-31.) Starting in the early 1980s, the number of institutions outside the ranks of the largest research universities (defined here as the top 100 in total 1995 R&D expenditures) with patent awards increased at a rapid pace. While the largest research universities had constituted 70 percent of all academic institutions receiving patents in 1982, their share of all academic institutions had fallen to just half in 1995—signaling a broadening of the institutional base, especially among public universities and colleges. (See appendix table 5-57.) Nevertheless, by 1995, 86 of the top 100 universities in total R&D expenditures received one or more patents.[76]

This expansion of the number of institutions receiving patents coincided with rapid growth in the number of patent awards; this latter rose from 458 in 1982 to 1,860 in 1995. Public institutions expanded their patenting activity somewhat more rapidly than did their private counterparts: the former received 64 percent of newly issued academic patents in 1995, up from 53 percent in 1982. At the same time, the

[75]No exact count or correlation with research dollars spent is possible, since patent ownership patterns depend on individual university or university system practices, which vary across institutions and over time. Patents may be assigned to boards of regents, individual campuses, subcampus organizations, separately created entities affiliated with one or more universities, or entities without any university affiliation. This discussion is based on data aggregated in consistent fashion to individual institutions or university systems, as the case may be, starting in the 1980s.

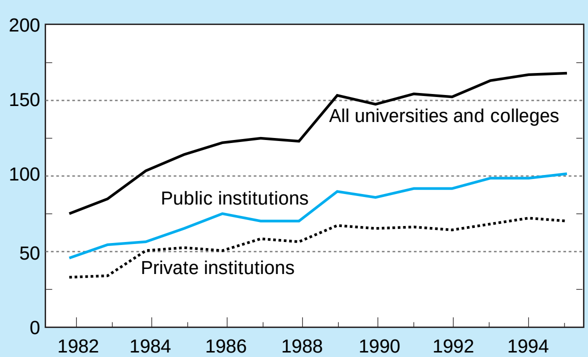
[76] This is a minimum estimate, since patent awards to some universities—e.g., University of California campuses—are generally recorded at the system level.

top 100 R&D-performing institutions increased their share of the expanding academic patent base from about three-quarters to over 80 percent of the total, where it has leveled off. (See appendix table 5-57.)

The number of academic patents rose more than sevenfold in just over two decades, from about 250 annually in the early 1970s to more than 1,800 in 1995. (See figure 5-32.) This is a far more rapid increase than for all annual U.S. patent awards, which roughly doubled over the period. As a result, academic patents now constitute about 3 percent of all new awards, up from less than one-half of 1 percent two decades ago. A change in U.S. patent law may have contributed to the strong rise in the 1980s; the law now allows academic institutions and small businesses to retain title to inventions resulting from federally supported R&D. Other contributing factors may be the creation of specialized university technology transfer and patenting units, an increased focus on commercially relevant technologies, and closer ties between scientific and engineering research and technological development (see Henderson, Jaffe, and Trajtenberg 1995).

Patents are assigned to utility classes according to their likely areas of application. The distribution of all patents over these areas has evolved slowly, but for academic patents, two pronounced changes have taken place. The growth in the number of academic patents was accompanied by a decrease in the number of utility classes in which they fall. In addition, academic patents are more heavily concentrated in relatively few application areas than are all U.S. patents. This is not surprising, since many patents in many application areas are not science-based at all. Nevertheless, the concentration is remarkable. Over the entire period covered by the database, 1969-95, utility classes in which universities were at least twice as likely as others to be awarded patents accounted for 12 percent of all patents, but half of all academic patents. (See appendix table 5-58.) A heavy concentration is evident in areas connected with the life sciences, along with some areas of physics and chemistry. (See appendix table 5-59.) In fact, the fraction of academic patents in just three utility classes—all with presumed biomedical relevance[77]—jumped from 8 percent of the total in the early 1970s to more than a quarter in the mid-1990s. (See figure 5-33.)

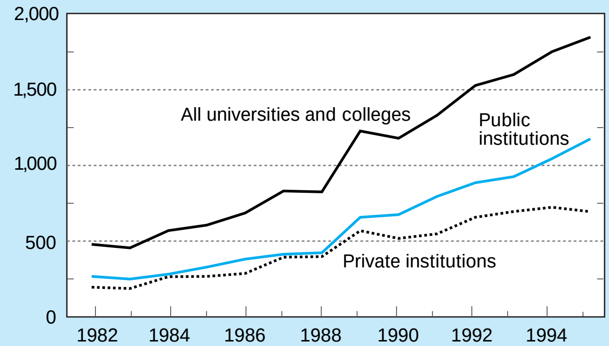
Figure 5-31.
Number of universities and colleges granted patents



NOTE: Data reflect lower bound numbers because of some university systemwide reporting.

See appendix table 5-57. *Science & Engineering Indicators – 1998*

Figure 5-32.
Number of academic patents granted



See appendix table 5-57. *Science & Engineering Indicators – 1998*

Income From Patenting and Licensing Arrangements

Valuation of patents—especially of science-based ones—is difficult. Actual use is uncertain, there is generally no direct connection between an individual patent and an economically valuable product or process, and acquisition of licensing rights may be motivated by protection rather than by intent to use. Nevertheless, universities increasingly are negotiating royalty and licensing arrangements based on their patents. While total reported revenue flows from such licensing arrangements remain low, a strong upward trend points to the confluence of two developments: a growing eagerness of universities to exploit the economic potential of research activities conducted under their auspices, and readiness of entrepreneurs and companies to recognize and invest in the market potential of this research.

A 1992 survey by the U.S. General Accounting Office based on 35 universities found that they had substantially expanded their technology transfer programs during the 1980s. Typical licensees were small U.S. pharmaceutical, biotechnology, and medical businesses. During 1989-90, the reported income flows based on these licenses were modest: a mere $82 million. A more extensive survey conducted periodically since 1991 (AUTM 1996) reported gross revenue receipts of $299 million in 1995, compared with $130 million in 1991. (See text table 5-14.) The survey—while extensive—is not nationally representative; thus, these estimates must be seen as lower bound numbers. Moreover, a portion of these reported revenue increases reflects expanded coverage.

[77]Utility classes number 424 and 514 capture different aspects of "Drug, bio-affecting and body treating compositions"; utility class number 435 is "Chemistry: molecular biology and microbiology."

Text table 5-14.
Overview of academic patenting and licensing activities

	1991	1992	1993	1994	1995
Gross royalties (million $)	130	172.4	242.3	265.9	299.1
New research funding from license (million $)	NA	NA	NA	106.3	112.5
Invention disclosures received	4,880	5,700	6,598	6,697	7,427
New patent applications filed	1,335	1,608	1,993	2,015	2,373
Total patents received	NA	NA	1,307	1,596	1,550
Startup companies formed			916[a]	175	169
Number of revenue-generating licenses, options	2,210	2,809	3,413	3,560	4,272
New licenses and options executed	1,079	1,461	1,737	2,049	2,142
Equity licenses and options				464[b]	99
Royalties paid to others (million $)	NA	NA	19.5	20.8	25.6
Unreimbursed legal fees expended (million $)	19.3	22.2	27.8	27.7	34.4
Sponsored research (billion $)	11.5	12.8	14.9	16.1	17.2
Industry-funded research	0.9	1.0	1.2	1.4	1.4
Federally funded research	8.1	9.1	10.1	10.7	11.4
Number of institutions responding	90	93	115	120	127

NA = not available

[a]Startup companies reported to have been formed through 1993.

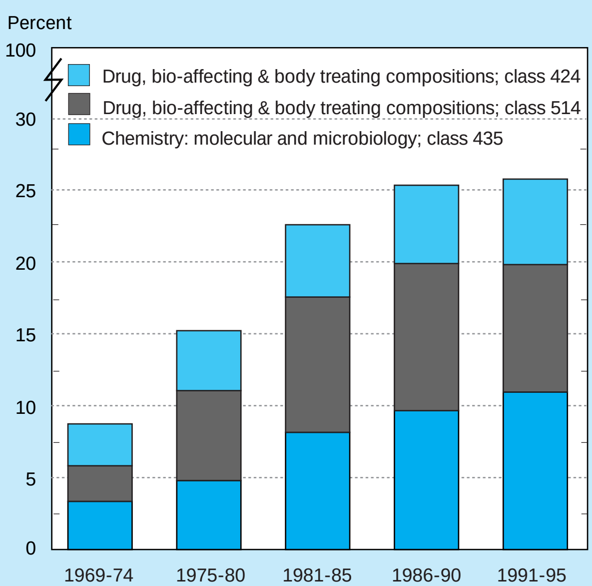
[b]Equity licenses and options granted through 1994.

NOTES: Figures on patenting differ from those reported for all universities and colleges by the U.S. Patent and Trademark Office since they do not reflect the activities of all U.S. universities and colleges. Data are internally consistent for each year shown but cannot be treated as trend data because of the growing number of institutions participating in the survey and varying nonparticipation of major research universities.

SOURCE: Association of University Technology Managers, Inc., AUTM Licensing Survey, Fiscal Year 1991-Fiscal Year 1995.

Science & Engineering Indicators – 1998

Figure 5-33.
Percentage of total academic patents in three utility classes



See appendix table 5-59. *Science & Engineering Indicators – 1998*

Conclusion

Academic R&D and S&E educational activities have long been a significant part of the U.S. R&D enterprise. R&D spending by universities and colleges is projected to reach $23.8 billion in 1997, accounting for an estimated 12 percent of total national R&D expenditures. The academic sector also continues to be the single largest performer of basic research, accounting for an estimated 52 percent of national basic research expenditures. The bulk of funding for academic R&D is provided by the Federal Government (60 percent in 1997); the second largest funding source is higher education institutions themselves (19 percent). State and local governments contribute 8 percent of the total, and industry and all other sources combined account for about 7 percent each. The bulk of federal funding is provided by three agencies: the National Institutes of Health with 57 percent, the National Science Foundation with 15 percent, and the Department of Defense with 10 percent.

Extensive physical infrastructure exists in support of academic R&D. About $3.1 billion in expenditures for constructing new *research facilities* were planned for 1996-97, along with another $1.3 billion for repair and renovation. Since 1988 (when comparable data first became available), academic S&E research space has increased by 22 percent, to 136 million net assignable square feet. New construction projects initiated between 1986 and 1995 which will either replace existing or add new space are expected to produce over 52 million square feet of research space by the time they are completed. In 1996, deferred construction or renovation projects totaled $9.3 billion, of which $7.4 billion was carried on approved construction plans. The major facilities funding sources are state governments (38 percent) and the institutions themselves (23 percent). Expenditures for *research equipment* were running just below 6 percent of total 1995 R&D expenditures. The major funder of research equipment remains the Federal Government (59 percent in 1995). In 1996, academic institutions rated 37 percent of their research laboratory space as suitable for the most scientifically competitive research; 44 percent as possibly needing some repair or renovation but effective for most levels of research; and 19 percent as needing major repair, renovation, or replacement. Overall, 27 percent of in-use research instruments were judged to be state of the art, another 63 percent as adequate for researcher needs, and 9 percent as inadequate.

About half of the nation's doctoral S&E research workforce was located in academic institutions—roughly 153,500 in 1995, including postdoctorates. The number of academic doctoral scientists and engineers reporting research as their primary work responsibility continued to grow, reaching 83,000 in 1995. Much of the growth, especially since the mid-1980s, occurred outside the traditional research universities; the number of institutions in this segment with federal R&D support reached 654 in 1995, up from 335 in 1975. In the course of their work, academic researchers are supported by, and help train, about 330,000 full-time S&E graduate students. For about 90,000 of them, a research assistantship was their most important means of support in 1995. The Federal Government is the primary source of support for about half of these students. In fact, RAs have grown in importance. The proportion of graduate students with research assistantships as their primary means of support increased from 22 to 27 percent between 1980 and 1995. A larger percentage of graduate students in the physical sciences, the environmental sciences, and engineering rely on RAs as their primary mechanism of support than do students in other disciplines.

Academic researchers produced 71 percent of all U.S.-authored scientific and technical articles in an international core set of peer-reviewed natural science and engineering journals included in the Institute for Scientific Information's Science Citation Index, and 23 percent of the world output published in these journals. (The total U.S. article share in 1995 was 33 percent.) Academic scientists and engineers increasingly collaborate with colleagues elsewhere: in 1995, nearly a quarter of all academic articles involved one or more authors from another U.S. employment sector.

Academic research, though predominantly basic, is increasingly connected with potential practical applications. More than 1,800 patents were awarded to academic institutions in 1995, which represented over 3 percent of all U.S. patent grants in that year. Academic patents were concentrated in a smaller set of application areas than patents of other awardees, with significant strengths in the life sciences, physics, and chemistry. In fact, more than a quarter of all academic patents fell into only three application areas with presumed biomedical relevance. Income from patenting and licensing agreements continued to grow and reached $299 million in 1995. And the number of citations to scientific and technical articles on patent applications, which has risen strongly in recent years, exceeded 47,000 in 1996—roughly 26,000 of which were to academic articles.

The increasingly global nature of the scientific and engineering enterprise is reflected in an ubiquitous increase in the number of articles that have authors from more than one country. Roughly half of the 439,000 articles published worldwide in the SCI journal set referred to earlier had authors from multiple institutions, and nearly 30 percent of these multi-author papers involved international collaboration. Two complementary trends characterize the U.S. position. For almost every nation with strong international coauthorship ties, the number of papers involving U.S. researchers rose strongly over the past decade and a half. But during this period, many nations broadened the reach of their international collaborations, leading to a gradual diminution of the U.S. share of articles involving international collaborations.

Citations to scientific and technical articles offer an indication of the perceived utility of the results of previous work in subsequent research. In a given country's literature, citations to local work tend to figure prominently and have less of a time lag than citations to work published abroad. But U.S. authors tend to be cited by scientists in virtually all mature scientific nations in excess of the U.S. world share of articles in chemistry, physics, biomedical research, and clinical medicine; U.S. articles in the remaining fields tend to be cited at or slightly below the U.S. share. But no other country cites the domestic literature as heavily as the United States—67 percent in 1995—probably reflecting, at least in part, the sheer scale of the nation's scientific and technical enterprise.

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